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Research Article

Epidemiology of Cholera: Patterns, Risk Factors, and Global Health Implications

Sylvester Chibueze Izah[1], Carmilla Ijeoma Udensi[2], Esther Nsikak Etim[3], Godwin Joshua[4], Nsikak Godwin Etim[5]

[1]Department of Community Medicine, Microbiology Faculty of Clinical Sciences, Bayelsa Medical University, Yenagoa, Bayelsa State, Nigeria
[2]Department of Medical Laboratory Science, Faculty of Health Sciences and Technology, University of Nigeria, Enugu, Enugu State, Nigeria
[3]Department of Medical Laboratory Science, Faculty of Basic Medical Sciences, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria
[4]Department of Public Health, Maryam Abacha American University of Niger, Maradi, Niger
[5]Department of Medical Laboratory Science, Faculty of Basic Medical Sciences, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria
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I N F O

Corresponding Author:
Syllvester Chibueze Izah, Department of Community Medicine, Faculty of Clinical Sciences, Bayelsa Medical University, Yenagoa, Bayelsa State, Nigeria
E-mail Id:
chivestizah@gmail.com
Orcid Id:
https://orcid.org/0000-0001-5526-006X
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A B S T R A C T

Cholera remains a significant global health challenge, especially in regions with poor water, sanitation, and hygiene (WASH) infrastructure. This paper examines cholera outbreaks' epidemiological patterns, risk factors, and global health implications. The paper showed through studies from high-burden countries from Asia, Africa, and the Americas the complex relationship among socioeconomic, environmental, and public health factors that contribute to the persistence of cholera in endemic regions. The primary risk factors for cholera transmission include contaminated water sources, poor sanitation, overcrowded living conditions, inadequate hygiene practices, and malnutrition. Additionally, displacement due to conflict or natural disasters further exacerbates the spread of the disease. This paper emphasises the critical role of improving WASH infrastructure, enhancing healthcare access, and strengthening surveillance systems in cholera control. Also, there is the need for collaborative efforts between governments, international organisations, and local communities, which are essential to reducing the global burden of cholera and achieving the Global Task Force on Cholera Control's (GTFCC) goal of ending cholera by 2030. Therefore, effective public health interventions must prioritise vulnerable populations and integrate tailored strategies to prevent and respond to cholera outbreaks.

Keywords: Cholera, Epidemiology, Global Health, WASH, Risk Factors, Surveillance, Vulnerable Populations

Introduction

The global distribution of infectious diseases is markedly uneven, influenced by various factors including geography, socioeconomic status, and public health infrastructure. Regions with limited healthcare access often experience higher prevalence rates of diseases such as tuberculosis, cytomegalovirus infection, etc., which pose significant public health challenges.[1,2] The complexities of diagnosing these diseases further exacerbate the situation, as inadequate diagnostic tools can hinder effective management and treatment. Moreover, food adulteration has emerged as a critical public health concern, contributing to the spread of infectious diseases, and necessitating robust mitigation strategies.[3]

The global burden of cholera remains a significant public health challenge, particularly in endemic regions where access to clean water and sanitation is limited. Cholera, caused by the bacterium *Vibrio cholerae*, leads to acute watery diarrhoea and can result in severe dehydration and death if not treated promptly.[4-6] Recent estimates indicate that there are approximately 2.9 million cases of cholera annually, with a mortality rate ranging from 21,000 to 143,000 deaths per year, predominantly in sub-Saharan Africa.[7,8] Socioeconomic factors often exacerbate the disease, as cholera is frequently found in impoverished communities with inadequate water, sanitation, and hygiene (WASH) services.[9,10] Understanding the epidemiological patterns of cholera is crucial for effective public health interventions and resource allocation.

Understanding epidemiological patterns in cholera is important. Epidemiological data provide insights into the transmission dynamics of cholera, identifying hotspots where the disease is most prevalent and where interventions can be most effectively targeted.[11] For instance, studies have shown that cholera outbreaks are closely linked to environmental factors, including water quality and climatic conditions, which can influence the incidence of the disease.[12] Furthermore, the identification of high-risk populations, such as children under five years of age, who are disproportionately affected by cholera, is essential for tailoring vaccination and treatment strategies.

Moreover, the economic burden of cholera is substantial, particularly in low-income countries where healthcare resources are limited. The costs associated with cholera outbreaks extend beyond direct medical expenses, including lost productivity and the economic impact on communities.[13] For example, a model-based estimation of the financial burden of cholera in Africa highlighted the potential cost-effectiveness of oral cholera vaccines (OCVs) as a preventive measure.[13] Countries can significantly reduce the incidence of cholera and its associated economic costs by investing in vaccination campaigns and improving WASH infrastructure. In Nigeria, cholera remains a persistent public health issue, with outbreaks occurring regularly, probably due to inadequate sanitation and water supply.[9,14] The Global Task Force on Cholera Control (GTFCC) has set ambitious targets to eliminate cholera by 2030, emphasising improved access to clean water and sanitation facilities.[9,11] Progress in expanding WASH services in Nigeria, where access to improved sanitation increased from about 50% to 60% between 2000 and 2020, is a positive step towards reducing cholera transmission. However, continued efforts are necessary to ensure these services reach the most vulnerable populations.

The role of climate change in influencing cholera outbreaks is also a growing area of concern. Research has indicated that climatic events, such as El Niño, can alter the distribution and incidence of cholera in Africa, complicating control efforts.[12] Changes in rainfall patterns and temperature can affect water quality and availability, thereby impacting the transmission of *Vibrio cholerae*.[10,12] Understanding these climatic influences is essential for developing adaptive strategies to mitigate the impact of cholera in a changing environment. Surveillance and data collection are critical components of cholera control efforts. Enhanced cholera surveillance systems can improve the efficiency of vaccination campaigns and help identify outbreaks more rapidly.[15] However, the reliance on passive clinical surveillance often leads to underreporting of cholera cases, which can obscure the actual burden of the disease.[16] Improved data collection methods, including integrating environmental and demographic data, can provide a more comprehensive understanding of cholera epidemiology and inform targeted interventions.

The global response to cholera must also consider the emergence of antibiotic-resistant strains of *Vibrio cholerae*, which pose a significant challenge to treatment efforts.[14] The increasing prevalence of multidrug-resistant strains necessitates ongoing surveillance and research to understand these pathogens' genetic and phenotypic characteristics.[17] Addressing antibiotic resistance is crucial for ensuring effective treatment options remain available for cholera patients.

The paper examines cholera's historical and geographic distribution, highlighting past pandemics, endemic regions, and recent trends, including emerging hotspots. It also explores critical risk factors such as water, sanitation, and hygiene (WASH) deficiencies and the effects of climate change, flooding, and population movement. The paper also addresses the vulnerability of specific populations, such as refugees and children, to cholera, gaps in surveillance systems, and the effectiveness of public health interventions in controlling outbreaks.

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Historical and Geographic Distribution of Cholera

Cholera has a long and complex history marked by multiple pandemics and endemic regions. The historical and geographic distribution of cholera reveals significant patterns that have evolved and are influenced by various factors, including environmental conditions, human behaviour, and socio-political contexts. Understanding these patterns is crucial for addressing cholera outbreaks and preventing future occurrences. The first recorded cholera pandemic began in 1817 in India and spread globally, leading to seven pandemics that have shaped the epidemiology of the disease.[18] Each pandemic has had distinct geographic footprints, with the disease predominantly affecting regions in Asia, Africa, and the Americas. The seventh pandemic, which started in 1961, continues to affect many countries, particularly in Africa, where cholera remains endemic. As of recent reports, cholera is endemic in over 50 countries, with significant outbreaks occurring in regions with poor WASH infrastructure.[19,20]

Cholera pandemics have historically been linked to environmental factors affecting water quality. The bacterium thrives in aquatic environments, and its transmission is closely associated with contaminated water sources. For instance, the relationship between climate variability and cholera outbreaks has been well documented, with factors such as temperature, salinity, and zooplankton influencing *Vibrio cholerae* populations' dynamics.[21] This environmental context is crucial for understanding the geographic distribution of cholera, as regions prone to flooding or drought are often more susceptible to outbreaks.

In recent years, cholera hotspots have emerged in specific countries that face unique challenges exacerbating the disease's spread. Yemen, for example, has experienced one of the most significant cholera outbreaks in history, driven by ongoing conflict, poor sanitation, and limited access to clean water and healthcare.[22] Since 2016, millions of cases have been reported, with the conflict severely disrupting essential services and worsening public health conditions.[23,24]The situation in Yemen illustrates how humanitarian crises can create fertile ground for cholera transmission, highlighting the need for targeted interventions in conflict-affected areas.

Haiti is another significant cholera hotspot, particularly following the devastating earthquake in 2010 that led to a major outbreak.[25] The country's inadequate WASH infrastructure continues to pose a risk for cholera transmission, with sporadic outbreaks occurring despite efforts to improve sanitation and healthcare.[20,26] The interplay between natural disasters and cholera outbreaks is evident in Haiti, where the destruction of infrastructure has made the population vulnerable to waterborne diseases.

The Democratic Republic of the Congo (DRC) regularly experiences cholera outbreaks, particularly in regions along the Congo River. The high population density in urban areas and a lack of clean water and sanitation facilities contribute to the disease's persistence.[27,28] Similarly, Somalia faces ongoing cholera outbreaks exacerbated by conflict, displacement, and poor infrastructure. Frequent floods and limited access to safe drinking water further complicate public health, particularly in refugee camps and urban slums.[16,28]

Nigeria's cholera burden is particularly pronounced in the northern regions, where access to clean water and sanitation is limited. Seasonal rains and floods contribute to water contamination, fuellingthe spread of cholera in rural and urban areas.[29] The recurring nature of cholera outbreaks in Nigeria underscores the need for improved water management and sanitation practices to mitigate the disease's impact. Bangladesh has long been vulnerable to cholera, especially in coastal and riverine areas where flooding frequently contaminates water sources. The country's high population density and poor sanitation infrastructure create ideal conditions for cholera transmission, particularly during monsoon seasons.[20,30] India's northern and northeastern states also experience cholera outbreaks from overcrowded urban areas and reliance on contaminated water sources.[20,31,32]

South Sudan's cholera outbreaks are common, particularly among displaced populations and in areas with poor infrastructure.[33] Conflict, flooding, and inadequate sanitation facilities have led to recurring outbreaks, highlighting the challenges humanitarian organisations face in responding to such crises.[29,32] Mozambique, particularly after natural disasters like cyclones and floods, also experiences cholera outbreaks, with vulnerable water and sanitation systems creating conditions conducive to transmission.[20,27,34]

Kenya frequently witnesses cholera outbreaks, especially in informal settlements and refugee camps where access to clean water and sanitation is severely limited.[35] Coastal regions and areas around Lake Victoria are particularly vulnerable, with seasonal rains exacerbating the situation.[27,36] Ethiopia faces similar challenges, with cholera outbreaks occurring during droughts or floods that affect water quality, particularly in refugee camps and regions with insufficient healthcare infrastructure.[16,32]

Zambia is another country where cholera is endemic, with outbreaks occurring frequently during the rainy season. Poor urban sanitation and inadequate access to clean water drive cholera transmission, necessitating comprehensive public health interventions (Ricau et al., 2021; Park et al., 2022). Zimbabwe has also experienced periodic cholera outbreaks, often linked to urban areas with crumbling infrastructure and water supply issues, particularly following the economic crisis 2008 (Sidiq, 2023; Abye et al., 2022).

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Sudan's cholera outbreaks are frequent, especially in conflict-affected regions and areas with inadequate water and sanitation infrastructure.[37] Flooding and displacement further exacerbate the situation, making it imperative to address the underlying causes of cholera transmission in these vulnerable areas. Tanzania's coastal regions and urban centers are similarly prone to cholera outbreaks, with vulnerable populations often relying on contaminated water sources.[38]

The recent trends in cholera outbreaks indicate a concerning pattern, with many countries experiencing recurrent epidemics due to a combination of environmental, social, and political factors. The World Health Organisation (WHO) has reported that cholera remains a significant public health challenge, particularly in regions with high poverty levels and inadequate infrastructure. The need for a multi-faceted approach to cholera prevention and control is evident, involving improved WASH infrastructure, enhanced surveillance, and timely response to outbreaks.

Key Risk Factors

Cholera remains a significant public health concern, particularly in regions with inadequate water and sanitation infrastructure. The primary risk factor for cholera transmission is contaminated water sources. The bacterium *Vibrio cholerae*, responsible for cholera, is predominantly transmitted through water contaminated with faecal matter. Studies have consistently shown that drinking or using untreated water from contaminated sources, such as rivers, lakes, and wells, is a significant risk factor for cholera outbreaks. For instance, research conducted in Haiti during the early phases of the cholera epidemic highlighted that contaminated water was a critical factor in the rapid spread of the disease, particularly during rainy seasons when waterborne transmission was most prevalent.[39] Similarly, investigations in Ethiopia confirmed that cholera outbreaks were closely linked to the consumption of contaminated drinking water, emphasising the role of aquatic environments in cholera transmission.[40] Table 1 provides an overview of the critical risk factors for cholera transmission and corresponding mitigation strategies.

Table 1.Key Risk Factors for Cholera Transmission and Corresponding Mitigation Strategies

Risk Factor	Narrative	Impact on Cholera Transmission	Mitigation Strategies
Contaminated water sources	Use of untreated or contaminated water from rivers, lakes, or wells	Primary mode of transmission of *Vibrio cholerae*	Ensure access to clean, treated water (e.g., chlorination, filtration)
Poor sanitation	Inadequate sewage systems and open defecation contaminate water sources	Increases water and food contamination with cholera bacteria	Improve sanitation infrastructure, proper waste disposal
Crowded living conditions	Overcrowded environments (e.g., refugee camps) with limited sanitation facilities	Facilitates rapid person-to-person and environmental transmission	Improve water, sanitation, and hygiene (WASH) facilities
Lack of access to clean water	Limited access to treated or safe drinking water	Increases reliance on contaminated water sources	Provide consistent access to clean, safe water
Inadequate hygiene practices	Poor handwashing and hygiene practices	Promotes hand-to-mouth transmission of the bacteria	Promote regular handwashing with soap, especially after using the toilet
Consumption of contaminated food	Food prepared with contaminated water or consumed raw	Contaminated food, particularly seafood, can spread cholera	Ensure food safety through proper cooking and use of clean water
Seasonal factors	Heavy rainfall, floods, and natural disasters lead to water contamination	Seasonal increases in cholera cases, especially during floods	Strengthen flood prevention and water management systems
Malnutrition	Weakened immune system due to poor nutrition	Increases susceptibility to infection and severity of disease	Improve nutrition programs and food security
Travel to endemic areas	Visitors to endemic regions may consume contaminated water or food	Higher risk of exposure and transmission	Vaccination and education on safe water and food consumption practices

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Weak public health infrastructure	Limited resources for outbreak detection and response	Delays in outbreak containment and higher fatality rates	Strengthen healthcare infrastructure, early detection, and rapid response
Displacement and conflict	People in conflict zones or disaster-hit areas lack clean water and sanitation.	Increased vulnerability to large-scale outbreaks	Provide emergency WASH services and shelter during crises

Poor sanitation practices further exacerbate the risk of cholera transmission. Inadequate sewage disposal and the lack of proper sanitation facilities can lead to the contamination of both water supplies and food sources with cholera bacteria. Open defecation and insufficient waste management practices significantly increase the likelihood of cholera outbreaks. For example, a comprehensive analysis of cholera risk factors in Nairobi County, Kenya, indicated that areas with limited access to sanitation facilities were particularly vulnerable during rainy seasons, which often led to the contamination of water sources.[41] Furthermore, studies in Uganda have shown that poor sanitation conditions correlate with increased cholera incidence, particularly in densely populated areas where open defecation is common.[42] This highlights the critical need for improved sanitation infrastructure to mitigate cholera risk.

Crowded living conditions are another significant risk factor for cholera transmission. Overcrowded environments, such as refugee camps and urban slums, facilitate the rapid spread of cholera due to limited access to clean water and sanitation facilities. High population density can amplify the risk of person-to-person transmission, as individuals living in close quarters are more likely to meet contaminated surfaces or water. Research has demonstrated that cholera outbreaks are more prevalent in densely populated areas, particularly during rainy seasons when sanitation systems are overwhelmed.[43] In Mozambique, cholera outbreaks were closely associated with high population density and poor sanitation practices, particularly during the rainy season.[44]

Lack of access to clean water is a critical risk factor for cholera outbreaks. Regions with limited access to safe, treated water are at a higher risk of cholera transmission, as individuals often resort to using untreated or improperly treated water for drinking, cooking, and washing. Studies have shown that communities relying on unsafe water sources are significantly more susceptible to cholera outbreaks. For example, research in Nigeria indicated that areas with inadequate access to clean water experienced higher rates of cholera-related deaths during outbreaks.[45] Additionally, a study in Bangladesh highlighted the correlation between water quality and cholera incidence, demonstrating that communities with access to safe drinking water had lower infection rates.[46] This emphasises the urgent need for interventions to improve access to clean water to prevent cholera outbreaks.

Inadequate hygiene practices also play a crucial role in the transmission of cholera. Poor personal hygiene, such as failing to wash hands with soap after using the toilet or before handling food, can significantly increase the spread of cholera. Hand-to-mouth transmission is a standard route for the bacteria to enter the human body. Research has shown that communities with poor hygiene practices are at a greater risk of cholera outbreaks. For instance, a study in Bangladesh found that improved hand hygiene practices were associated with reduced cholera incidence.[47] Similarly, findings from a case-control study in Ethiopia indicated that individuals who practised better hygiene were less likely to contract cholera.[40] This highlights the importance of promoting hygiene education and practices as a preventive measure against cholera.

The consumption of contaminated food is another significant risk factor for cholera transmission. Eating raw or undercooked seafood from contaminated waters or food prepared with contaminated water poses a substantial risk. Street food, which is often prepared in unsanitary conditions and may be washed with unsafe water, is particularly concerning. Research has shown that foodborne transmission of cholera is a significant contributor to outbreaks, especially in regions where seafood is a dietary staple. For example, a study in India found that consuming raw seafood was linked to increased cholera cases during outbreaks.[48] This underscores the need for food safety measures and public awareness campaigns to reduce the risk of cholera transmission through contaminated food.

Seasonal factors also play a critical role in cholera transmission dynamics. Cholera outbreaks are often linked to rainy seasons, floods, and natural disasters, which can contaminate water sources and overwhelm sanitation systems. Seasonal variations in rainfall and temperature can significantly affect water quality and the transmission patterns of cholera. For instance, research has shown that heavy rain and flooding are commonly cited risk factors for cholera outbreaks in sub-Saharan Africa.[43] Additionally, studies in Zanzibar have demonstrated that seasonal changes in climate, such as increased rainfall

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and temperature, are associated with elevated cholera risk .[49] This highlights the need for seasonal preparedness and response strategies to mitigate the impact of climate-related factors on cholera transmission.

Malnutrition is another crucial risk factor that exacerbates susceptibility to cholera. Malnourished individuals, particularly children, are more vulnerable to cholera due to their weakened immune systems. Studies have shown that malnutrition not only increases the likelihood of contracting cholera but also exacerbates the severity of the infection, leading to higher mortality rates. For example, research in Bangladesh indicated that malnourished children had a significantly higher risk of severe cholera and related complications.[46] This highlights the importance of addressing malnutrition as part of comprehensive cholera prevention strategies, particularly in vulnerable populations.

Travel to endemic areas also poses a risk for cholera transmission. Individuals travelling to regions where cholera is endemic are at increased risk, especially if they consume untreated water or food. The lack of proper vaccination or preventive measures raises the risk for travellers. Studies have indicated that travelers to cholera-endemic regions are more likely to contract the disease, particularly if they do not adhere to safe food and water practices.[50] This highlights the importance of providing travel health advice and vaccination options for individuals travelling to areas with known cholera outbreaks.

Weak public health infrastructure significantly hampers efforts to manage cholera outbreaks effectively. Countries with underfunded or underdeveloped public health systems struggle to promptly detect and respond to cholera outbreaks. Delayed detection, lack of access to healthcare, and inadequate outbreak response exacerbate the spread of cholera. Research has shown that regions with robust public health systems are better equipped to manage cholera outbreaks and reduce mortality rates.[45] This emphasisesthe need for investment in public health infrastructure to enhance cholera prevention and control efforts.

Displacement due to conflict or natural disasters often forces individuals into unsanitary conditions, increasing vulnerability to cholera outbreaks. Displaced populations frequently lack access to clean water and healthcare, making them particularly susceptible to cholera. Studies have shown that cholera outbreaks are more prevalent in refugee camps and areas affected by conflict, where sanitation and healthcare services are severely limited.[51] This highlights the importance of addressing the needs of displaced populations and ensuring access to clean water and sanitation facilities to prevent cholera outbreaks in these vulnerable groups.

Vulnerable Populations and Health Inequities

Cholera poses a significant public health threat, particularly to vulnerable populations. Among these populations, children under five are particularly susceptible due to their immature immune systems, malnutrition, and increased exposure to contaminated water and food sources. Research indicates that cholera can lead to rapid dehydration and death in young children if not treated immediately, highlighting the critical need for timely interventions and access to healthcare services for this demographic.[52,53] The World Health Organisation(WHO) emphasises that children are at a higher risk of severe dehydration, which can escalate rapidly without proper medical attention, stressing the importance of preventive measures such as vaccination and improved sanitation.[54] Table 2 and Figures 1 and 2 highlight the vital vulnerable populations, associated risk factors, health inequities, and impacts of cholera outbreaks.

Table 2.Major vulnerable populations, associated risk factors, health inequities, and impacts of cholera outbreaks

Vulnerable Population	Risk Factors	Health Inequities	Impact
Children under 5 years	Weaker immune systems, poor nutrition, exposure to contaminated water and food	Limited access to healthcare, malnutrition, and poor sanitation	High mortality rate due to rapid dehydration and severe illness
Pregnant women	Increased risk of dehydration, complications during pregnancy	Limited healthcare access, especially in rural/low-income areas	Increased risk of miscarriage, preterm labor, and severe illness
Immunocompromised individuals	Weakened immune systems due to HIV/AIDS, tuberculosis, etc.	Inadequate healthcare support, especially in underserved areas	Higher risk of severe cholera and mortality due to compromised health
Displaced populations & refugees	Overcrowding, lack of clean water and sanitation facilities	Poor access to healthcare and public health interventions	Higher incidence of cholera outbreaks and poor treatment outcomes

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Low-income communities	Reliance on contaminated water sources, poor sanitation	Economic barriers to accessing healthcare and clean water	Increased vulnerability to cholera outbreaks and higher death rates
Rural populations	Limited access to healthcare, clean water, and sanitation	Infrastructure disparities between urban and rural areas	Delayed treatment and increased cholera-related mortality
Women and girls	Increased exposure due to household responsibilities (fetching water, managing sanitation)	Gender-based disparities in healthcare access	Higher risk of infection and delayed treatment
Ethnic minorities & marginalized groups	Social exclusion, lack of access to clean water and healthcare	Discrimination in access to public health interventions	Greater exposure to cholera and poor health outcomes

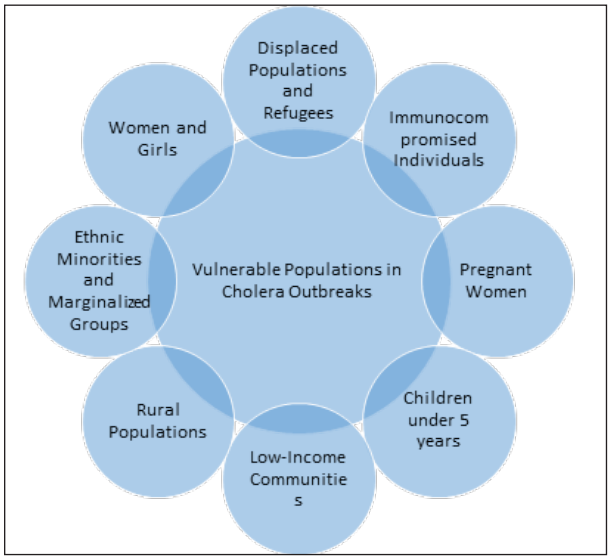

Figure 1.Vulnerable populations in cholera outbreaks

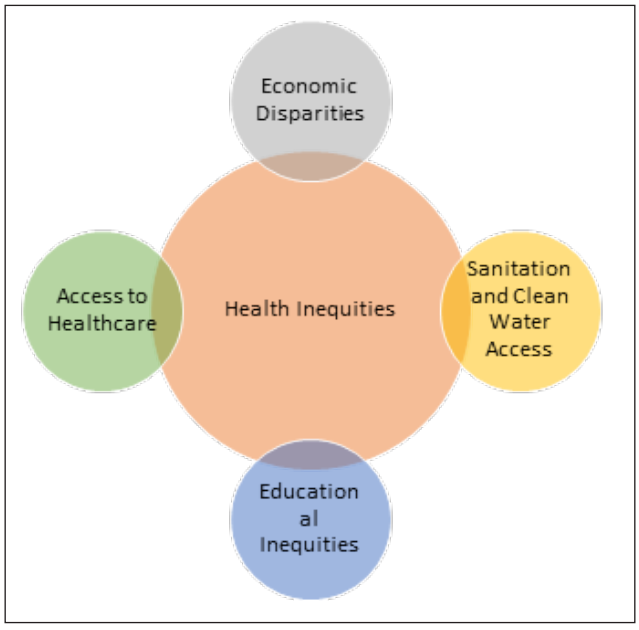

Figure 2.Health inequities associated with cholera outbreaks

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Pregnant women also represent a vulnerable group during cholera outbreaks. The physiological changes that occur during pregnancy can exacerbate the effects of cholera, leading to complications such as preterm labour, miscarriage, and severe dehydration.[52,55] Studies have shown that pregnant women infected with cholera are at a significantly higher risk of adverse outcomes, including foetal death, particularly when they experience severe maternal dehydration.[56,57,58] Access to healthcare is often limited for pregnant women, especially in low-income settings, which can further increase the likelihood of poor health outcomes during cholera outbreaks.[52,59] Therefore, targeted interventions, including the provision of cholera vaccines during pregnancy, are crucial to mitigate these risks.[52]

Immunocompromised individuals, including those living with HIV/AIDS or other chronic conditions, face heightened risks during cholera outbreaks. Their weakened immune systems make them more susceptible to severe cholera infections, which can lead to increased morbidity and mortality.[53,60] In regions where HIV/AIDS and tuberculosis are prevalent, the compounded health threat posed by cholera can overwhelm healthcare systems that are already strained.[53,60] Research indicates that immunocompromised patients often experience more severe symptoms and poorer outcomes following cholera infection, emphasising the need for integrated healthcare approaches that address both infectious diseases and underlying health vulnerabilities.[53,60]

Displaced populations and refugees are particularly vulnerable to cholera outbreaks due to their living conditions, which often include overcrowding and inadequate access to clean water and sanitation facilities. Refugee camps and internally displaced persons (IDP) camps frequently lack the necessary infrastructure to prevent the spread of waterborne diseases.[53,61] The Yemeni civil war, for example, has resulted in a significant cholera outbreak exacerbated by limited access to safe drinking water and healthcare services.[62] The combination of poor hygiene practices, overcrowding, and lack of access to medical care creates an environment ripe for cholera transmission, necessitating urgent humanitarian interventions to improve water, sanitation, and hygiene (WASH) conditions in these settings.[53]

Low-income communities are disproportionately affected by cholera due to systemic inequities that limit access to clean water, sanitation, and healthcare services. Poverty often forces these communities to rely on unsafe water sources, increasing their risk of cholera infection.[54,63] Furthermore, the lack of infrastructure in low-income areas makes it challenging to implement effective public health interventions, such as vaccination campaigns and sanitation improvements.[54,63] Economic disparities exacerbate health inequities, as wealthier populations can afford private healthcare and safe water supplies, while low-income individuals remain vulnerable to preventable diseases like cholera.[54,63]

Rural populations, particularly in low-income countries, face unique challenges in combating cholera outbreaks. Limited healthcare infrastructure in rural areas often results in delayed detection and treatment of cholera cases, leading to higher mortality rates. Access to clean water sources and sanitation facilities is often inadequate, further increasing vulnerability to cholera. The geographical isolation of rural communities can hinder timely public health responses, making it essential to develop targeted strategies that address the specific needs of these populations during cholera outbreaks.

Women and girls may be often disproportionately affected by cholera outbreaks due to their roles in managing household water and sanitation. In many societies, women are primarily responsible for fetching water, which increases their exposure to contaminated sources. Gender-based inequalities can further limit women's access to healthcare, making it more difficult for them to seek treatment during cholera outbreaks. Addressing these gender disparities is crucial for improving health outcomes and ensuring that women and girls receive the necessary support during cholera outbreaks.[54,63]

Ethnic minorities and marginalised groups often experience discrimination and exclusion from public health interventions, which can exacerbate their vulnerability to cholera outbreaks. These groups may have limited access to clean water, sanitation, and healthcare services, increasing their risk of infection.[54,63] Socio-political factors can further hinder their access to essential health services, leading to poorer health outcomes during cholera outbreaks. It is necessary to adopt inclusive public health strategies that consider the unique needs of marginalised populations to combat cholera and reduce health inequities effectively.

Health inequities play a significant role in the vulnerability of populations to cholera outbreaks. Disparities in access to healthcare services can lead to delayed treatment and higher mortality rates among vulnerable groups. The gap between urban and rural healthcare availability is pronounced in many low-income regions, with rural populations often lacking access to timely medical interventions.[54,63] Addressing these disparities is critical for improving health outcomes and ensuring all individuals have access to the care they need during cholera outbreaks.

Sanitation and clean water access are fundamental determinants of health that significantly influence cholera transmission. Inequities in access to safe drinking water

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and adequate sanitation infrastructure are key drivers of cholera outbreaks, particularly in vulnerable populations.[4] Many individuals in low-income communities live in areas where these basic needs are unmet, leading to increased exposure to cholera bacteria. Improving WASH conditions is essential for preventing cholera and reducing health inequities among vulnerable populations.[4]

Economic disparities further exacerbate the impact of cholera on vulnerable populations. Impoverished communities often rely on unsafe water sources and lack the financial means to afford medical treatment, increasing their risk of severe cholera infections. This economic vulnerability can create a cycle of poor health outcomes, as individuals who contract cholera may face additional financial burdens due to lost income and medical expenses. Addressing economic disparities is crucial for improving health equity and reducing the burden of cholera on low-income populations.[54,63]

Educational inequities also contribute to the vulnerability of populations during cholera outbreaks. Lack of awareness and health education in marginalised and low-income communities can lead to poor hygiene practices, such as unsafe water storage and consumption.[4,5,6] These practices increase the risk of cholera transmission and highlight the need for targeted health education initiatives that promote safe hygiene practices.[54,63] By improving health literacy in vulnerable communities, public health officials can enhance the effectiveness of cholera prevention efforts.

Surveillance Systems and Data Gaps

Surveillance systems for cholera outbreaks are crucial for timely detection and response to this devastating disease. These systems encompass various methodologies, including early warning systems, global surveillance networks, and national programs aiming to monitor and report cholera cases effectively. Early warning systems, for instance, utilise real-time reporting from health facilities, community-based surveillance, and mobile health technologies to identify suspected cases of cholera quickly. This rapid detection is essential for initiating control measures, such as vaccination campaigns and public health interventions, to mitigate the spread of the disease.[64,65] Table 3 and Figure 3 present an overview of surveillance systems and data gaps in cholera outbreaks.

Table 3.Surveillance Systems and Data Gaps in Cholera Outbreaks

Aspect	Description	Challenges	Impact
Early Warning Systems	Real-time reporting systems to detect outbreaks, often through health facilities or community reports.	Weak health infrastructure and delayed reporting.	Delays in identifying outbreaks, hindering rapid response.
Global Surveillance	Networks like GTFCC and WHO monitor cholera outbreaks globally through sentinel sites and labs.	Underreporting and inconsistent global collaboration.	Incomplete global data, making tracking difficult.
National Programs	Country-specific systems integrated into broader public health systems to track cholera cases.	Resource limitations and varying reporting standards between countries.	Inconsistent data makes comparisons across regions hard.
Case Reporting	Standardized case definitions and reporting at local, national, and international levels.	Incomplete reporting, particularly in conflict zones or remote areas.	Reduced understanding of cholera spread in vulnerable areas.
Underreporting	Many cases go unreported due to access issues and weak health infrastructure.	Lack of healthcare access and confirmation testing in remote areas.	Gaps in outbreak data, underestimating the disease burden.
Data Collection Gaps	Inconsistent methods across countries lead to differences in cholera tracking.	Inadequate frameworks and lack of trained personnel.	Limited ability to compare or aggregate global data.
Real-Time Data Issues	Delays in data collection and reporting, especially in regions without digital infrastructure.	Poor internet access and technical limitations in low-resource areas.	Outdated data, reducing the effectiveness of response efforts.

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Geospatial Data Gaps	Lack of precise geographic data on outbreak locations.	Minimal mapping capacity and poor integration with other health data.	Difficulties in targeted interventions and response.
Resource Constraints	Lack of financial and technical support for maintaining surveillance systems.	Limited capacity for timely detection, testing, and reporting.	Weak surveillance leads to uncontrolled outbreaks.
Laboratory Capacity	Need for confirmation of suspected cholera cases through lab testing.	Inadequate laboratory resources in many affected regions.	Uncertainty in data complicates outbreak verification.

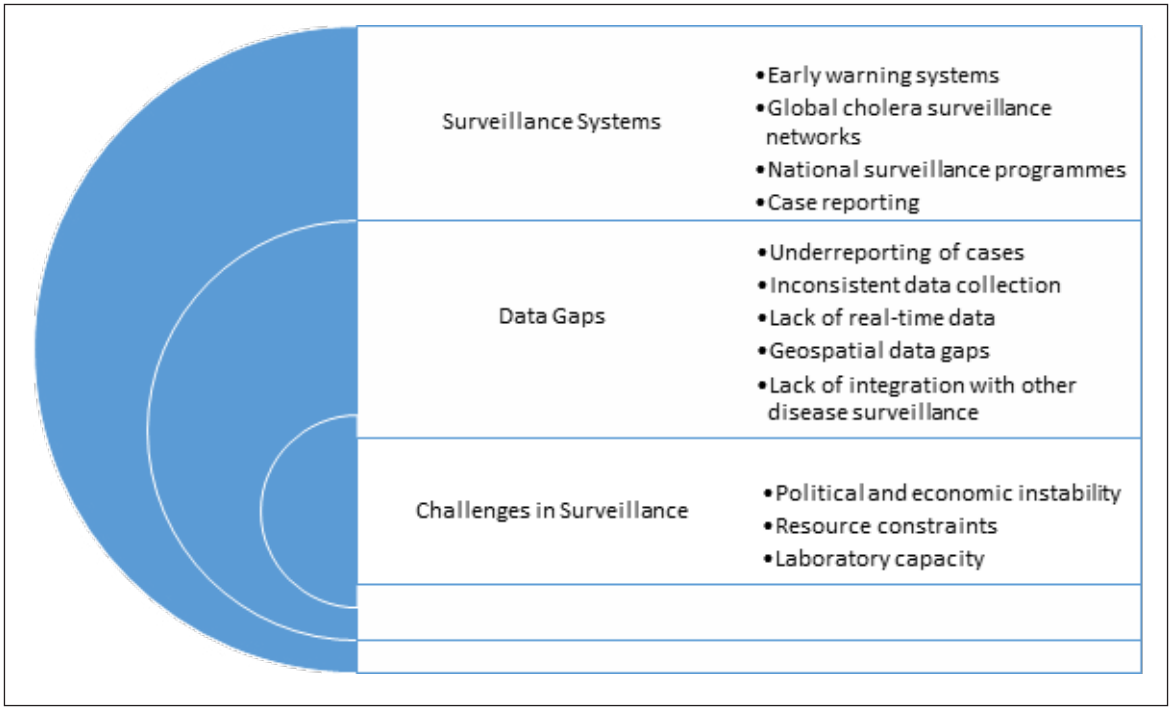

Figure 3.Surveillance Systems and Data Gaps in Cholera Outbreaks

Global initiatives like the Global Task Force on Cholera Control (GTFCC) and the WHO are vital in cholera surveillance. These organisations facilitate the establishment of sentinel surveillance sites and promote laboratory confirmation of cholera cases, which is necessary for accurate outbreak tracking. The GTFCC aims to reduce cholera mortality by improving surveillance and response strategies globally, while the WHO provides standardisecase definitions and reporting frameworks that enhance the comparability of data across different regions.[66,67] Such global networks are instrumental in coordinating efforts to combat cholera, particularly in endemic regions with the highest disease burden. At the national level, countries implement surveillance programs, often integrated into broader public health information systems. The effectiveness of these national programs can vary significantly based on available resources, infrastructure, and political stability. For example, in countries with robust health systems, cholera cases are more likely to be reported accurately, while in regions with limited healthcare access, underreporting remains a significant challenge. This discrepancy highlights the importance of strengthening national surveillance capabilities to ensure comprehensive data collection and reporting.[7,68]

Case reporting for cholera typically occurs at local, national, and international levels, following standardised definitions established by the WHO. However, underreporting is pervasive, particularly in countries with weak health infrastructure. Studies have indicated that reported cholera cases may only represent a fraction of the actual incidence, with estimates suggesting that only 5-10% of confirmed cases are reported to the WHO.[7,67] This underreporting can be attributed to various factors, including limited access to healthcare facilities, lack of laboratory confirmation, and the stigma associated with cholera, which may deter individuals from seeking treatment.[7,69]

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Data gaps in cholera surveillance systems pose significant challenges to understanding the true extent of outbreaks. One major issue is the underreporting of cases, particularly in remote or marginalisedareas where healthcare access is limited. This lack of reporting can lead to significant gaps in data, hindering public health responses and the ability to implement effective interventions.[42,45] Furthermore, inconsistent data collection methods across different countries and regions create challenges in comparing cholera incidence and outbreak patterns, complicating global tracking efforts.[68,70]

Another critical data gap is the lack of real-time data collection and reporting. In many cholera-endemic regions, delays in reporting can severely hinder rapid response efforts. For instance, areas with limited digital infrastructure may struggle to implement real-time surveillance systems, resulting in outdated or incomplete data on cholera outbreaks.[15,71] This delay can have dire consequences, as timely information is essential for mobilising resources and implementing control measures to prevent further spread of the disease.

Geospatial data gaps also present significant challenges in cholera surveillance. In many endemic regions, detailed geospatial data is insufficient to understand where outbreaks are occurring and how they are spreading geographically. This lack of information complicates the implementation of targeted interventions, such as vaccination campaigns and water sanitation efforts, which are crucial for controlling cholera outbreaks.[14,72] Improved geospatial data collection and analysis could enhance the effectiveness of public health responses to cholera.

Moreover, cholera surveillance systems often lack integration with other disease surveillance frameworks. This disconnection can lead to missed opportunities for tracking the interplay between cholera and other waterborne diseases, such as typhoid fever and dysentery. Integrating cholera surveillance with broader public health monitoring systems could provide a more comprehensive understanding of disease dynamics and facilitate coordinated responses to outbreaks.[73,74] Such integration is critical in regions where multiple infectious diseases coexist, allowing for a more comprehensive approach to public health.

Challenges in cholera surveillance are further exacerbated by political and economic instability in affected regions. Surveillance systems are often disrupted in areas experiencing conflict or political turmoil, leading to significant data gaps and hampered response efforts. Resource constraints also play a critical role; many countries facing cholera outbreaks lack the financial and technical resources necessary to maintain robust surveillance systems, which affects their capacity for timely case detection and reporting.[45,75] Strengthening these systems is essential for improving cholera control efforts.

Laboratory capacity is another critical factor influencing cholera surveillance. A lack of laboratory resources can prevent the confirmation of suspected cholera cases, leading to uncertainty in outbreak reports and data accuracy. In many cholera-affected countries, laboratory facilities are limited, and the necessary training for healthcare workers is often insufficient. This inadequacy can result in misdiagnosis or failure to identify cholera cases, further complicating surveillance efforts.[71,76] Enhancing laboratory capacity is vital for improving the reliability of cholera surveillance data.

Public Health Interventions

Effective cholera prevention and control strategies are critical for reducing the incidence of this waterborne disease. Key interventions include enhancing access to clean water, improving sanitation facilities, and promoting hygiene practices. These measures are essential for breaking the transmission cycle of *Vibrio cholerae*, the bacterium responsible for cholera. The WHO emphasizes that comprehensive WASH interventions can significantly reduce cholera outbreaks and improve overall health outcomes in endemic regions.[7,77] Furthermore, health education is pivotal in empowering communities to adopt preventive measures, reducing the risk of cholera transmission.[78]

Mass vaccination campaigns using OCVs have emerged as a vital tool in cholera control, particularly in high-risk areas. Studies have shown that targeted vaccination efforts can effectively reduce cholera incidence, especially in densely populated urban settings and during outbreaks. For instance, implementing OCVs in cholera hotspots in Guinea-Bissau has demonstrated a marked decrease in disease transmission.[79] Integrating vaccination with other public health strategies, such as improved sanitation and health education, has proven effective in controlling cholera outbreaks .[75] This multifaceted approach addresses immediate health concerns and contributes to long-term resilience against cholera in vulnerable populations.

Case studies from various countries illustrate the effectiveness of coordinated cholera interventions. In Bangladesh, OCV deployment, community engagement, and rapid response mechanisms have significantly reduced cholera cases.[75] Similarly, Haiti's cholera response efforts, which included mass vaccination and enhanced surveillance, have shown promising results in curbing the spread of the disease.[43,75] These examples underscore the importance of tailored interventions considering local contexts and community dynamics. Engaging communities in planning and implementing cholera control strategies can foster ownership and enhances the sustainability of public health initiatives.

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The role of environmental factors in cholera transmission is crucial. Research indicates that cholera outbreaks are often linked to specific environmental conditions, such as poor sanitation and contaminated water sources.[80] In the Democratic Republic of the Congo, recurrent cholera outbreaks have been associated with geographic hotspots and inadequate water management practices.[81] Understanding these environmental drivers is crucial for developing effective cholera prevention strategies. Interventions must focus on immediate health measures and address the underlying ecological determinants of health, such as access to safe water and sanitation facilities.[4,77]

Moreover, the economic implications of cholera outbreaks highlight the need for sustained investment in public health infrastructure. Cholera poses a direct health threat and incurs significant financial costs, including healthcare expenditures and lost productivity.[82] Countries with endemic cholera face ongoing challenges in mobilizing resources for effective prevention and control measures. Therefore, integrating cholera control strategies into broader economic development plans is essential for achieving long-term health improvements and reducing the burden of disease.[7,77] This approach aligns with global health initiatives, such as the Sustainable Development Goals (SDGs), which emphasisethe importance of universal access to safe water and sanitation.[77]

In addition to infrastructural improvements, enhancing community awareness and education about cholera prevention is vital. Studies have shown that knowledge of cholera transmission and prevention practices is often limited, particularly in rural and underserved communities.[78] Public health campaigns that focus on educating individuals about the importance of hygiene, safe water practices, and the use of vaccines can significantly improve community resilience against cholera outbreaks. Furthermore, engaging local leaders and health workers in these educational efforts can help to build trust and encourage community participation in cholera prevention initiatives.[75]

Therefore, surveillance and rapid response systems in cholera control are crucial. Effective surveillance enables the timely detection of cholera cases, which is vital for implementing rapid response measures to contain outbreaks.[75] Countries with robust surveillance systems and community-based reporting mechanisms have demonstrated improved outcomes in managing cholera epidemics.[42,75] Continuous monitoring and evaluating cholera interventions are essential for adapting strategies to changing epidemiological patterns and ensuring that resources are allocated effectively.

Conclusion and Global Health Implications

The fight against cholera requires robust global cooperation, transcending borders, and sectors. The Global Task Force on Cholera Control (GTFCC)'s goal of eliminating cholera by 2030 underscores the urgent need for countries, international organisations, and local communities to unite efforts to improve WASH conditions, strengthen surveillance systems, and ensure equitable access to healthcare. Cholera disproportionately affects vulnerable populations in low-resource settings, and coordinated interventions, such as OCV campaigns, rapid response teams, and health education, arecrucial for reducing the spread of this preventable disease. By fostering collaboration, resource sharing, and collective action, the global health community can significantly reduce the burden of cholera, particularly in hotspots such as Yemen, Haiti, and sub-Saharan Africa.

Future research in cholera epidemiology must focus on understanding the evolving dynamics of the disease, particularly in the context of climate change, migration, and urbanisation. This includes identifying new risk factors, improving the effectiveness of vaccines, and exploring innovative strategies for early detection and intervention. Further, addressing data gaps in cholera surveillance systems is essential to developing more effective response mechanisms. Research should also emphasise the socio-economic determinants of cholera, evaluating how poverty, inequality, and inadequate infrastructure exacerbate the disease's spread. Strengthening these research efforts will improve cholera control and enhance global preparedness for other waterborne diseases.

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