Epidemiology and Public Health Strategies against Cholera: The Role of Climate Change and Antimicrobial Resistance

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Abstract

Cholera is a major disease worldwide that causes severe diarrhea due to *vibrio cholera*, and is ideally in regions with a high level of poor sanitation with low accessibility to clean water. The chapter deals with epidemiology, including all environmental parameters in relation to their contribution to the cholera ecosystem, such as climate change and antimicrobial resistance (AMR). Climate change is one of the most important factors affecting the epidemiology of cholera rising temperatures and alterations in rainfall patterns become frightening changes due to extreme events such as floods and droughts in tropical parts of the world. Increasing antimicrobial resistance is further adding to the complications for successful cholera control however, some classical treatments for cholera are threatened by the potency of such resistances. The chapter discusses the important public health strategies including vaccination campaigns, improved water sanitation and hygiene (WASH), and early warning systems. An integrated approach to cholera prevention must target the premises at both environmental and microbial levels, interventions in climate adaptation, and robust AMR surveillance systems. Due to these emerging threats, the mitigation of the public health burden of cholera should rest upon multi-sector collaborations.

Keywords: Cholera, Epidemiology, Climate Change, Climate Adaptation, Antimicrobial resistance

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Introduction

Cholera is one of the most outstanding public health challenges across the globe particularly in areas where there is no access to clean water, sanitary conditions of living, and any form of effective healthcare services. It is an acute diarrheal disease caused by the bacterium *vibrio cholera* (Baldi et al., 2009). Cholera causes severe dehydration, and if not treated, it carries the risk of death. Even with advances in the treatment of water, sanitation, and even vaccination, cholera continues to thunder and manages to hold itself out in endemic areas situations where, yet an important public health concern. Primary transmission of cholera is by water, with the major agents being contaminated drinking water and food (Rabbani & Greenough III, 1999). Poor hygiene practices, overcrowded living conditions, and environmental conditions all make this public health problem confined and spread the disease even to people who live within reach of modern healthcare infrastructure.

Recent studies show that climate change significantly contributes to the frequency and intensity of cholera outbreaks. Indeed, altered rainfall patterns along with increased global temperatures and extremes of flooding and drought have made the environment conducive to cholera epidemics (Sathyendranath et al., 2020). The bacterium grows well in a warm nutrient-rich environment and fluctuating climatic conditions would have increased the water source contamination that would eventually lead to its spread in regions that had previously been less affected. As climate change continues to disrupt natural weather patterns and environmental conditions, the risk of cholera transmission will likely increase in the vulnerable parts of the world, representing an increasingly difficult challenge for public health (Christaki et al., 2020).

Climatic changes have compounded the problem of AMR increasingly related to *vibrio cholera*. Misuse and overuse of antibiotics have given rise to resistant strains of the bacteria and thus reduced therapeutic options as well as complicated efforts for the management of cholera outbreaks (Sack et al., 2001). The public health threat posed by antibiotic resistance in cholera is significant, making it problematic to treat infected individuals and increasing the risk of worse outcomes. This cause as factors lead to AMR being endemic in cholera regions thus inappropriate use of antibiotics in humans and animals, and also the presence of resistant bacteria within an environmental source.

A multi-pronged approach combining mitigation of climate change, improved sanitation, vaccination campaigns, and well-developed surveillance systems to monitor the spread of disease fits into ongoing efforts that need to be directed toward addressing the cholera threat

(Ganesan et al., 2020). Public health strategies must therefore be specific, with recognition of adaptation to climate and environmental conditions to address the environmental determinants that add to cholera transmission. Moreover, the disease of AMR entails an increase in antibiotic resistance development of diagnostic capacities for treatment to ensure the correct prescribing of the therapy (Ahmed et al., 2024). Beyond this, there is the need to access a broad system health infrastructure and a fairly well-designed compulsory purchase of water, sanitation, and healthcare services against cholera.

This chapter deals with the epidemiology of cholera, the effects of climate change in terms of the diseases it transmits, and the increasing threat from AMR as shown in Figure 1. It considers key public health strategies for cholera prevention and control together with adaption in facing new challenges (Craig, 2018). This also explores the complex realities around dealing with modern cholera through the dialogues between elements of climate change, antimicrobial resistance, and public health interventions and offers possible future solutions for reducing the global burden of the disease.

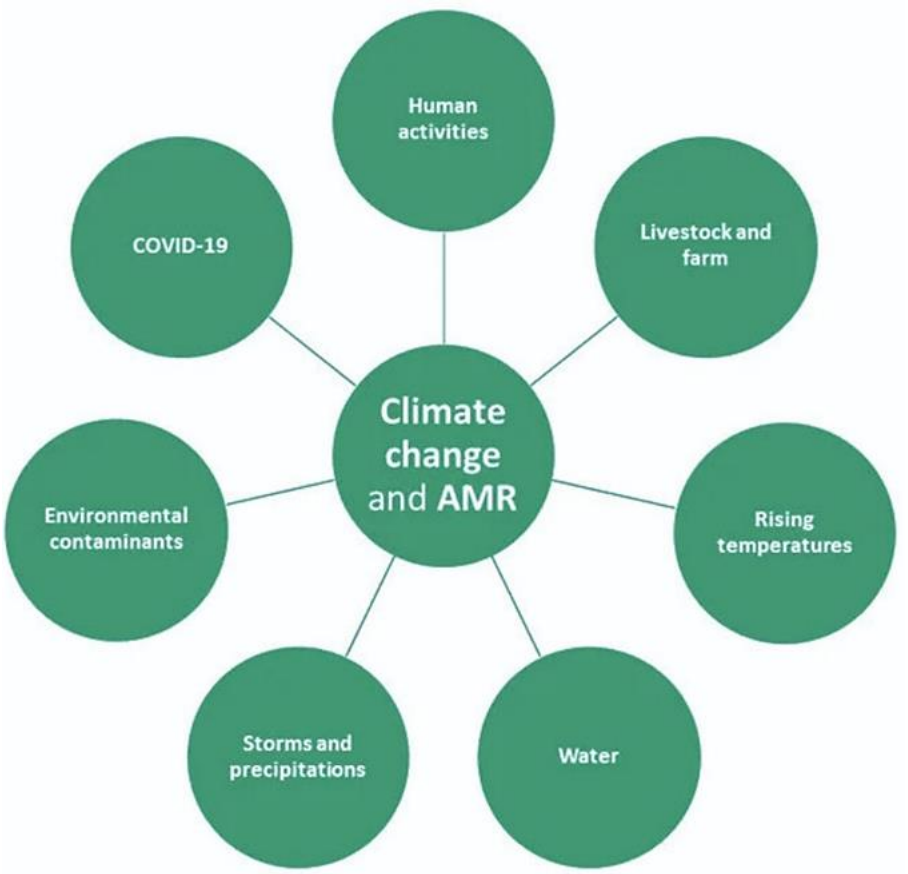

Fig. 1: The main factors involved in the relationship between climate change and antimicrobial resistance (Retrieved from Canva Pro).

Epidemiology of Cholera

Cholera is a very dangerous infectious disease that is caused by the bacterium *vibrio cholera*. It is primarily characterized by acute watery diarrhea and extreme dehydration (Kuna & Gajewski, 2017). It is still a major public health concern in poor resource settings without ready access to clean water, sanitation, and healthcare services. The global burden of cholera varies greatly in different localities, facing the heaviest toll within areas of Sub-Saharan Africa, South Asia, and parts of Latin America. Cholera is usually spread along with epidemics, however, at times it can also be found endemically in areas where there is continuous transmission (Balasubramanian et al., 2021). Epidemiological study of cholera includes knowing the wheels of distribution, various transmission mechanisms as well as the most susceptible human populations.

The incidence of cholera varies very much during the course of time. Major epidemics occur at periodic intervals from one part of the globe to the other (Jutla et al., 2013). Areas that suffer cholera outbreaks always, in the greatest measure, lack a proper and adequate sanitation system and good access to safe drinking water, and overcrowded living conditions surely facilitate the transmission of cholera (Musa, 2018). Disease is transmitted predominantly through the fecal- oral route, where contaminated water and food serve as the major vehicles for infection. However, cholera can also be transmitted through contact with contaminated surfaces or when consuming undercooked shellfish from waters contaminated with the *vibrio cholera* bacterium. The bacterium is best suited to grow in those environments where the sanitation infrastructure has very limited clean water resources (Moe & Rheingans, 2006).

In addition to these direct environmental factors, there are socio-economic conditions that have an impact when it comes to cholera transmission. Poor populations lacking adequate health care, health education, and nutrition are at greater risk of suffering from cholera (Charnley et al., 2022). Thus, typical vulnerable categories among affected people include children, the elderly, and immunocompromised hosts susceptible to significant dehydration, the leading cause of death relating to cholera that is not addressed. Outbreaks are propitious in general, most affected areas observe natural disasters, armed conflicts, or displacements, where the people have their networks disrupted, and accessing

clean water becomes limited (Hotez, 2021).

Cholera occurs in every corner of the globe however, some regions undergo a permanent or cyclical pattern of dissemination. The Bay of Bengal area in South Asia, especially Bangladesh and India, is understood to be the cholera core of the world with recurring outbreaks in relation to seasonal factors mainly induced by monsoons or floods (Shackleton et al., 2024). The country's rich African heritage has kept this tropical disease alive in some parts of Africa, especially along the African Great Lakes, where poor sanitation and seasonal rainfall conditions increase the chances of cross-contamination. Major cholera outbreaks that have occurred recently in Latin America, especially Haiti, confirmed the long-standing persistence of cholera in areas that were considered previously in the low-risk outfits.

Climate changes present new challenges to the epidemiology of cholera. Changes in temperature, precipitation patterns, and the frequency of extreme weather events such as flooding and drought increasingly alter the dynamics of transmission of *vibrio cholera* (Christaki et al., 2020). Higher temperatures can promote the invasion of new areas by the bacterium, while erratic rainfall events lead to contamination of water sources and increased cholera spread. The correlation between climate variability and cholera outbreaks is particularly apparent during events when unusual weather patterns create very good opportunities for the organism to proliferate in the environment.

Cholera is one of the most manageable diseases it is only in certain areas of the world because controlling it has many hurdles. Improved sanitation and safe water sources are vital in preventing transmission. Oral rehydration therapy (ORT) and antibiotics are useful, but their usefulness depends on timely and appropriate diagnosis and intervention. AMR in cholera disease aggravates the complications with treatment because resistant strains decrease the effectiveness of standard antibiotics, posing a much greater threat to global health (Sparrow et al., 2024).

Surveillance and monitoring systems are essential for the early detection of outbreaks within highly vulnerable areas (Meckawy et al., 2022). Early intervention through the provision of clean water and oral cholera vaccines, coupled with improved health services, results in a significant potential reduction in the impact of cholera outbreaks. Addressing the direct causative factors for cholera, such as poor sanitation and climate change, requires long political and inter-sectoral public health strategies for cooperation between all governments, international organizations, and communities (Mabuza, 2020).

1. Public Health Strategies against Cholera

It has made its unavoidable presence in everyday life by being part of a critical public health issue even in those areas of the world where there is bad sanitation and less access to clean water. Such effective strategies are to prevent, control, and treat cholera infection whereby there is an emphasis on hygiene improvement, water sanitation, surveillance, and vaccination (D'Mello-Guyett et al., 2020). The public health strategies would help decrease the burden of illness and will also prevent the spread and thus eventually eliminate this disease as a threat in cholera endemic areas.

i. Water, Sanitation, and Hygiene (WASH) Interventions

Drinking Water, Sanitation, and Hygienic Practices will ultimately prevent cholera from being transmitted. Contaminated water and food are the major transmission modes, so quality drinking and sanitation infrastructure is a basic approach to the cholera control program. The use of safe drinking water prevents cholera. Most public health interventions in scope include improvements to water treatment systems, including filtering, chlorination, safe boreholes, wells, and piped water networks (Organization, 2009).

Sanitation Infrastructure: In this respect, improving sanitation with proper sewage systems and safe disposal of waste minimizes the possibility of the contamination of the water supply. In rural or economically deprived areas lacking sewerage systems, latrines or compost toilets should be promoted in the community to reduce fecal matter propagation (Lüthi et al., 2009).

Hygiene Promotion: Basic hygiene practices should be encouraged. Washing hands with soap and careful handling of food infection. Public health will conduct campaigns on hygiene that promise to be very effective in reducing transmission risks, especially in communities where these practices are not generally adopted.

ii.Oral Cholera Vaccination (OCV)

Among other contributions, OCV makes crucial coverage in preventing cholera disease outbreaks in endemic areas and emergencies. Vaccination can prevent infection and lessen disease severity, and it is highly relevant in global measures against cholera.

Efficacy and Use of OCV: The efficacy of OCV vaccination campaigns at different match sites has been affirmatively proven, particularly in poor sanitation settings where cholera prevails in water and food. OCVs are orally administered and hence can be used in distant areas or those with fewer resources for distribution (Pezzoli, 2020).

Selective Vaccination Campaigns: Selective vaccination campaigns can be carried out to control cholera among high-risk populations during actual outbreaks and areas forecasted for local seasonal transmission (Gabutti et al., 2020). Mass vaccination campaigns for high-risk countries have been implemented by WHO and partners for the high-risk areas in regions.

Adoption of OCVs: OCVs are part of the routine immunization schedule for some places so that they can offer long-term immunity to the receiving population. This would achieve herd immunity in the communities and, thereby, cause reduced incidence rates of cholera.

iii. Treatment and Rehydration

It is essential to treat the infection effectively to reduce cholera-related morbidity and mortality. Timely detection and intervention in the early stages can save lives, and the treatment for cholera is ORT.

Oral Rehydration Therapy: By far, the most critical treatment to achieve for cholera is the rapid replenishment of fluids and electrolytes from diarrhea losses. ORT, a simple mixture of water, sugar, and salts, can be an inexpensive and effective intervention in the prevention of dehydration death.

Intravenous Rehydration: In severe cases of cholera, when patients suffer from extreme dehydration or inability to take fluids orally, IV rehydration may be required (Pietroni, 2020). This is offered mainly in health facilities.

Antibiotic Treatment: This has sometimes been used to shorten the duration of illness and lessen the severity of symptoms. However, with the increase in AMR, the treatment has become more complicated, as resistant strains will render most commonly used antibiotics ineffective.

iv. Surveillance and Early Detection

Such detection of cholera outbreaks on time is very vital in news scope and the propagation of advancement to be made in case of an outbreak. It enables them to prove rapid intervention for public health measures using vigilant anticipation for any outbreaks.

Monitoring and Reporting: Developing cholera endemic region surveillance systems is necessary for early observation (Ganesan et al., 2020). Constant observation monitoring health data and reporting systems as well as community based surveillance programs work to follow up on incidence rates in cholera cases and newly emerging hotspots.

Early Warning Systems: Putting in place early warning systems linking diseases and environmental data may predict before the event an expected cholera outbreak under seasonal weather conditions. Prompt actions include immunization campaigns or stockpiling of medical supplies.

v. Community Engagement and Education

Cholera control entails the participation and awareness of the community. The involvement of residents in preventive activities and the sensitization of the population on the dangers and the course of action taken when diagnosed with cholera can play a significant role in the incidence of the disease (Amicizia et al., 2019).

Community Health Workers: Trained community health workers are significantly involved in creating awareness and providing information to households on cholera prevention and the use of ORT and vaccination during outbreaks. Community health workers serve as the first contact for identifying cases and providing initial care.

Health Education Campaigns: Outbreaks can be prevented through health campaigns that educate communities regarding cholera transmission, drinking water safety, sanitation, and hygiene practices (Taylor et al., 2015). They could be run through various media like radio, television, and social media channels, as well as through community meetings and workshops.

Community Based Cholera Response: Community education alone is not enough, but empowerment could encourage communities to systematically act against cholera by improving local waters, digging latrines, and instituting hygiene measures that would consider preventive advantages.

vi. International Collaboration and Support

Cholera is indeed a transboundary disease applicable in many countries. This means that it's going to need global or regional collaboration in fighting cholera (Jones, 1998). International partnerships and support will be important in strengthening efforts toward cholera control systems and ensuring that resources are available where the need is greatest. To address the cholera problem on a global level, the WHO will be most responsible for coordinating cholera control efforts, such as the provision of technical assistance in outbreak situations or resource mobilization during outbreaks. Such an organization involves developing and distributing vaccines, diagnostic tools, and treatment protocols as shown in Figure 2.

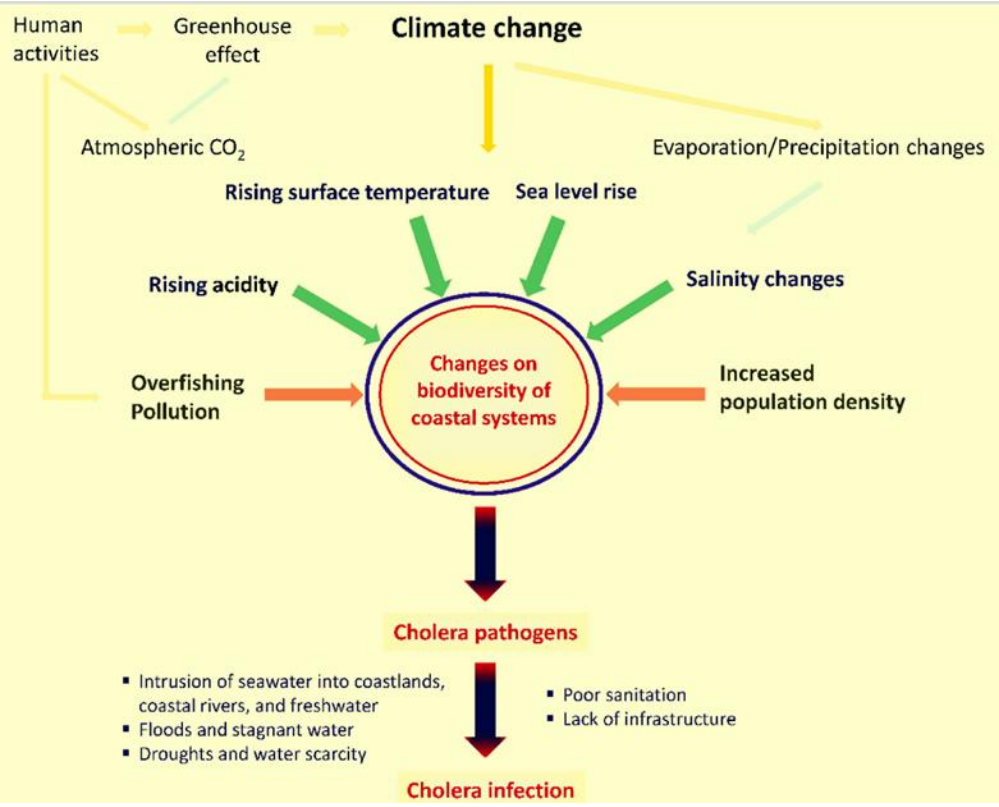

Fig. 2: Climate change on oceans and *vibrio cholera*: Schematic representation of the major drivers for cholera infection or cholera outbreaks (Retrieved from Canva Pro).

2. Addressing Antimicrobial Resistance

The AMR is raising the bar for the treatment and control of cholera, therefore, cholera treatment using standard antibiotics becomes very difficult. The main focus of such AMR actions is enhancing the stewardship of antibiotics, which requires appropriate usage (Majumder et al., 2020). They should not be prescribed unnecessarily, given at an appropriate indication, and given in the correct treatment regimens to prevent resistance.

Continuous surveillance of *vibrio cholera* strains for the development and dissemination of AMR is of utmost importance. This involves the detection of antibiotic resistance pattern changes and updating treatment protocols in reference to the latest findings. New antibiotics, vaccines, and treatment methods are needed to cope with resistant strains of *vibrio cholera* (Narendrakumar et al., 2019). Using probiotics, bacteriophage therapy, or other forms of non-antibiotic therapy is being considered as an alternative cholera treatment option.

3. The Role of Climate Change in Cholera Transmission

Further, climate change is increasingly acknowledged as a significant factor in infection dynamics in cholera the waterborne disease-causing bacterium, *vibrio cholera* (Rayan et al., 2021). This is because the organism thrives in warm, nutrient-rich environments and climatic shifts create a favorable environment for its propagation, especially in poorly equipped places with regard to water, sanitation, and hygiene.

i. Temperature Increases and *Vibrio Cholera* Proliferation

One of the factors contributing to an increase in cholera transmission worldwide is the rise in global temperature (Chowdhury et al., 2017). Warmer water or increased temperatures, particularly in coastal and riverine areas, is becoming more effective for the growth and survival of cholera. Warmer waters are more favorable for the multiplication of the bacterium, which in turn increases the chances of contamination of drinking water sources.

ii. Altered Rainfall Patterns and Flooding

Changes in precipitation patterns most significantly reflect the frequency and intensity of rainfall events and are thus strong contributors to cholera transmission (Asadgol et al., 2020). Heavy rainfall causes flooding that overwhelms sanitation systems, which in turn contaminates safe drinking water with *vibrio cholera*. Floods render treatment works dysfunctional and deny communities access to safe water, essential for preventing the disease (Johannessen et al., 2013). Drought reduces access to safe water sources and may force communities to rely on unsafe or possibly contaminated water sources.

iii. Extreme Weather Events and Cholera Outbreaks

Weather is Extreme Events, cyclones, hurricanes, and Typhoons, through which water is displaced. This condition leads to flooding often breaking into and polluting sources of water (Valavanidis, 2022). At this point, the outbreak of cholera, as these displaced people live in unsanitary crowded conditions, leaving these survivors with little access to clean water and sanitation.

iv. Ocean and River Currents Influencing Cholera Spread

There is increasing evidence that global warming alters the oceanic and river currents, which, in turn, affects the environmental distribution of *vibrio cholera* (Sedas, 2007). Changes in the current patterns of water bodies can transport bacteria from one area to another, thus facilitating cholera transmission (Usmani et al., 2021). For example, changing ocean currents can carry *vibrio cholera* water to new coastal areas that were previously risk-free, hence geographically expanding the spread of cholera.

6. Impact on Cholera Transmission in Endemic Regions

Climate change in cholera endemic areas may amplify the seasonal fluctuation related to cholera incidence. Rising temperatures associated with erratic rainfall patterns may prolong the cholera period and increase the number of cases occurring in a year (Lipp et al., 2002). Given the interface of climatic variables, localized environmental factors, and cholera transmission, it demonstrates the necessity for climate sensitive public health strategies to manage and mitigate outbreaks

7. Predictive Models and Early Warning Systems

Integration of climate data into cholera surveillance systems can predict cholera outbreaks. Early warning systems that include temperature and rainfall as climate variables can give predictions about possible cholera outbreaks, which can then lead to actions like vaccination campaigns and water sanitation efforts. Predictive models of this nature can become the most important tool for cholera control under climate change.

8. The Impact of Antimicrobial Resistance on Cholera Control

The emergence of AMR has been a growing challenge in the control of cholera, which is caused by *vibrio cholera*. Traditionally, antibiotics have played a major role in the severity and duration of cholera infection, especially in severe cases (Das et al., 2013). Today, the increasing emergence of resistant strains of *vibrio cholera* poses a significant threat to standard antibiotic treatment, thus complicating management further and exposing the already high risk of mortality in settings that are resource poor. AMR in cholera is propelled mainly by antibiotic overuse and misuse in human and animal health. Such drugs are administered oftentimes inappropriately without adequate medical supervision in the many cholera endemic regions of the world (Stepan et al., 2003). Therefore, this scenario leads to resistant strains of *vibrio cholera* that survive even with tetracycline and ciprofloxacin, two of the most used antibiotics for the disease. The resistant bacteria then contaminate water sources, misdirected waste disposal, and last but not least, the environmental dissemination of resistant bacteria makes this

problem tougher to deal with because the source of contamination is not easy to control thus, outbreaks will become more challenging.

This is an alarming feature of AMR in cholera as concerns its effectiveness against treatment. It means that cholera, which is resistant to antibiotics, can cause a protracted illness, lead to loss of body fluid, and increase the fatality risk. The use of antibiotics, which are generally administered with ORT to reduce the intensity of the disease, is diluted when the organism is resistant to additional standard treatments (WILLIAMS et al., 1986). In very extreme cases, this requires using alternative or more powerful antibiotics that may be less available in low-resource settings or more expensive, thereby compounding the already difficult issue in the management of cholera (Hall-Clifford, 2024).

Furthermore, AMR in cholera presents challenges to the overall efforts in the control of the disease. It can increase treatment costs, stretch already thin healthcare facilities, and complicate the control of outbreaks, especially in settings where the healthcare infrastructure is weak. Global concern also comes in the form of AMR proliferation since resistant strains can extend their reach into other territories and cause larger and more extensive outbreaks, making it more difficult to control the disease. To combat the effect of AMR, several measures should be put in place in designing strategies for cholera control. These measures include surveillance for monitoring resistant *vibrio cholera* strains, antibiotic stewardship activities to limit their unnecessary use, and improved diagnostics to ascertain the use of antibiotics where necessary. These interventions also include new investments in the research and development of newer antibiotics, vaccines, and alternative treatment modalities to ensure staying ahead of resistant strains (Saeed et al., 2023). In this case, public health will also focus on improvements in water, sanitation, and hygiene to avert/curtail cholera outbreaks and other waterborne diseases since such improvements will mitigate the risk of the emergence of resistance.

9. Integrated Approaches for Cholera Prevention and Control

Integrated strategies for cholera prevention and control are vital for minimizing the impact of cholera primarily in those areas where sanitation is lacking and clean drinking water is scarce (Challa et al., 2022). It is a disease that can be caused by drinking infected water or eating contaminated food thus, cholera prevention requires a multifaceted strategy, encompassing water, sanitation, and hygiene improvements as well as treatment and vaccination, surveillance, and community participation. Addressing immediate contributing factors to cholera and the deep-seated causes that render some communities more vulnerable to cholera is what the approaches seek to achieve.

Community engagement is critical for the effective containment of cholera. People have to become engaged in the education for themselves and others about prevention, sanitation projects that they participate in, and the formation of local collaboration response teams, which in turn strengthen interventions of public health. Community health workers can be most probably utilized for disseminating information, treatment, and encouraging preventive behaviors because they belong to those members of the community to whom trust is most close, and are often found inside the communities (Howard & Bogh, 2002). Similarly, involving communities in program design and implementation increases the chances for the sustainability of otherwise well-intended health interventions, building herd immunity and reducing diseases. WHO has fully backed the use of OCVs in cholera endemic regions as well as during emergencies where rapid vaccination can prevent the spread of the disease. Treatment also demands an important thing in an integrated cholera control strategy (Taylor et al., 2015). For cholera, the mainstay treatment remains ORT, while intravenous rehydration can be employed in severe cases. Early diagnosis and prompt treatment stop the flow of people dying because of dehydration, the number-one killer in cholera; ORT recommends its use in addition to antibiotics for very severe cases aimed at limiting the illness duration and possibly limiting transmission. Ensuring health facilities can manage cholera cases and training healthcare workers to provide the appropriate care from the framework for reducing the mortality rate.

An integrative approach to preventing and controlling cholera needs strong collaboration between the government, international organizations, non-governmental organizations (NGOs), and local communities (Baličević et al., 2023). Input from other sectors, such as health, sanitation, water, and education, will bring cooperation and proper alignment of resources for working and avoiding duplication. It is an approach that might address synergistically the complex and multifactorial nature of transmission and lead to long-term reduction in cholera morbidity and mortality.

Conclusion

Cholera continues to affect regions with less sanitation, limited access to clean water, and inadequate healthcare systems and is still a public health challenge. It is multifaceted since the effects, at environmental, social, and health levels, give rise to a complicated interplay and make cholera hard to prevent or control. However, such advances can come through integrated, diverse public health strategies with systems that combine. WASH interventions (i.e., water, sanitation, hygiene) with vaccination, effective treatment, early detection and surveillance, and community involvement. Indeed, in all such efforts combined, the cholera burden level would greatly reduced worldwide. These actions can help contain and prevent cholera infection despite all of these challenges. Sustained investment in infrastructure and health systems, along with research and continued collaboration, is the key to long-term lesion in combating cholera. The capacity to address underlying causes of cholera, coupled with timely and evidence based measures, will enable us to make significant strides toward achieving cholera free status on a global scale. The world, however, is not only destined to reduce mortality from cholera but also to put future generations in cholera-free environments, ultimately resulting in a world without cholera.

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