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Anticipatory action for cholera mitigation, Democratic Republic of the Congo

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A simulation-based policy analysis of anticipatory action for cholera outbreaks, Democratic Republic of the Congo

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Abstract

Objective To explore the effect of anticipatory action on outcomes during a cholera outbreak in a hypothetical health zone in the Democratic Republic of the Congo by means of a cholera response model.

Methods Using a system dynamics approach, we developed a cholera response model for the Democratic Republic of the Congo on the basis of a published cholera response simulation model for Yemen. The model evaluated four intervention scenarios: (i) existing responses to cholera outbreaks; (ii) anticipatory action (that is, immediate interventions); (iii) anticipatory action plus one vaccine dose; and (iv) anticipatory action plus two vaccine doses.

Findings The model showed that immediate interventions can function as an essential bridge to comprehensive vaccination, particularly in resource-constrained settings where timely coordination is crucial. Moreover, anticipatory action can reduce the total number of cholera cases. However, booster vaccinations are crucial for preventing subsequent waves of infection due to waning immunity following single-dose vaccination.

Conclusion Anticipatory action can enhance cholera outbreak management in low-resource settings by facilitating synergy between immediate and long-term interventions. The timing and coordination of interventions and the use of booster doses to prevent disease resurgence are all important. Dynamic models are useful for simulating outbreaks and can foster proactive, evidence-based, public health planning, thereby supporting the shift from reactive to anticipatory strategies in alignment with the Global Task Force on Cholera Control's 2030 cholera roadmap. Continuous refinement of the model with real-world data will enhance its global applicability and help advance effective disease control strategies.

Introduction

Cholera, caused by the *Vibrio cholerae* bacterium, remains a global health challenge, particularly in regions with inadequate water, sanitation and hygiene infrastructure.^{1,2} The disease causes severe symptoms such as watery diarrhoea and dehydration, which can be fatal without timely treatment. Although proper health care reduces the case fatality rate to below 1%, untreated cholera can result in a mortality rate as high as 70%.^{3,4}

The Democratic Republic of the Congo bears a disproportionate cholera burden. The country accounted for up to 14% of the estimated 1.34 to 4.01 million cases that occurred globally each year between 2008 and 2012.^{5,6} In 2017, the country experienced one of its worst outbreaks, with over 53 000 cases and 1145 deaths.⁵ Despite ongoing efforts, a resurgence in 2022 highlighted the persistent challenge of cholera control.⁷

Anticipatory action offers a proactive alternative to traditional reactive responses to events. This approach involves implementing pre-emptive measures to mitigate the impact of crises.⁸ Humanitarian agencies such as the International Federation of Red Cross and Red Crescent Societies, the United Nations Children's Fund and the World Health Organization (WHO) have increasingly adopted anticipatory action, with an emphasis on early warning systems, preplanned interventions and pre-arranged funding aimed at reducing the disease burden.^{9,10} This approach aligns with the Global Task Force on Cholera Control's roadmap for eliminating cholera as a public health threat by 2030.¹¹ Although anticipatory approaches have been explored in broader disasters,^{10,12} their inclusion in models of cholera interventions remains limited, despite the need for proactive strategies in high-burden settings like the Democratic Republic of the Congo.

Most previous cholera models have focused on reactive strategies. Researchers have analysed reactive vaccination and localized interventions during outbreaks,^{13,14} or discussed cholera transmission models that highlighted challenges such as parameter uncertainty and the need for a proactive approach.¹⁵ In a modelling study of a cholera outbreak in Yemen,¹⁶ researchers showed that early intervention could have prevented up to 40% of deaths compared with interventions one year later at the end of the epidemic curve. However, their study did not incorporate anticipatory action.

The aim of our study was to adapt and expand the Yemen cholera response model¹⁶ to investigate the effect of anticipatory action on cholera outcomes in the Democratic Republic

of the Congo. The model simulates the effect of different intervention scenarios and provides an insight into the use of proactive public health strategies in low-resource settings.

Methods

Our study used a system dynamics model to simulate the effect of cholera interventions in the Democratic Republic of the Congo. System dynamics modelling aims to provide an understanding of how complex systems behave over time by analysing feedback loops and causal relationships, which makes it particularly useful for health policy planning in low-resource settings.^{17,18} The model also provides a framework for investigating intervention scenarios, even when data availability is limited.¹⁹

We adapted a published Yemen cholera response model by building on the model's susceptible–infected–recovered–susceptible framework and by integrating water, sanitation and hygiene measures and health-care and vaccination interventions. In the susceptible–infected–recovered–susceptible framework, individuals transition between the states of being susceptible to infection, infected, recovered and susceptible again when they eventually experience waning immunity after recovery. To reflect local conditions in the Democratic Republic of the Congo, the model incorporated data for Nyiragongo, North Kivu, where there have been recurring cholera outbreaks and where public health resources are constrained.^{6,20} A detailed description of the original model structure is available in the original article.¹⁶

To isolate the systemic impact of interventions and to allow generalization to other settings with a high disease burden, the model used a hypothetical health-zone framework. This approach avoids confounding by context-specific factors such as conflict or population displacement (for example, internally displaced persons or refugee camps) and ensures the analysis focuses on broader population dynamics. Despite being hypothetical, the model's parameters were based on real demographic and epidemiological data from North Kivu, including population statistics and information on documented interventions and resource availability obtained from WHO reports, publications of the Democratic Republic of the Congo's health ministry and peer-reviewed studies (online repository).²³ Where data were incomplete, we incorporated plausible ranges of parameters into sensitivity analyses to estimate uncertainty and to ensure realistic and scalable insights could be derived for intervention planning.

Model data

Our cholera response model relied on three main data sources: (i) structural data, which were retained from the Yemen cholera response model's susceptible–infected–recovered–susceptible framework and which addressed general cholera transmission dynamics; (ii) epidemiological data, which were derived from the global and regional literature and which covered infection duration, vaccine immunity and other biological constants; and (iii) intervention data augmented by region-specific water, sanitation and hygiene data and health-care response data that reflected conditions in Nyiragongo.

As the primary aim of the study was to assess early outbreak responses at the population level, we did not disaggregate data by age, sex or gender. Moreover, there were data limitations and a need for model simplicity. We followed Sex and Gender Equity in Research guidelines where possible and remained aware of the importance of sex and gender in health research throughout our analysis.²¹

The model simulated cholera interventions over a 3-year period from 1 January 2022 to 1 January 2025. We used Stella Architect version 3.4.1 (isee systems, Lebanon, United States of America) for the simulations and Euler's integration method was applied with a time step of 0.25 days.²² We made adaptations to ensure the model reflected the local context in North Kivu: (i) case-area targeted interventions were introduced to simulate localized response strategies; and (ii) sewage treatment interventions were excluded due to a lack of sewage treatment facilities in the area.

Cholera dynamics

Fig. 1 shows a simplified version of the adapted cholera response model for the Democratic Republic of the Congo based on the susceptible–infected–recovered–susceptible framework. Detailed model descriptions and parameter values are provided in the online repository.²³

In the model, cholera transmission takes place primarily through contaminated water (that is, indirect infection), which is driven by bacterial shedding from infected individuals and an inadequate water, sanitation and hygiene infrastructure. In the Democratic Republic of the Congo, only an estimated 52% of the population has access to basic drinking water and over 7 million people practice open defecation, which underscores the urgent need for water, sanitation and hygiene interventions.^{24,25}

The infected population was divided into people who remain untreated and those who receive care, with two associated infection feedback loops (Fig. 1). In the treated infection feedback loop, individuals, who were typically managed at cholera treatment centres, did not

contribute to environmental contamination as their waste was disinfected, thereby reducing the spread of *Vibrio cholerae*.³ In the untreated infection feedback loop, individuals continued to shed bacteria into the environment, thereby driving indirect infection. In one study in Yemen,²⁶ only an estimated 32% of people with suspected cholera visited a cholera treatment centre on the day of symptom onset,⁵⁰ which delayed treatment and increased the risk of the disease spreading.

The cholera recovery time varies: asymptomatic cases recover within 5 days and symptomatic cases recover within 9 days.^{13,27} Severely infected individuals either recover with immunity or die during this time period.

The duration of immunity also varies: in symptomatic cases, immunity typically lasts 3 years, whereas, in asymptomatic cases, immunity may last only 3 to 12 months.^{2,28} Waning immunity leads to individuals becoming susceptible again, which highlights the necessity of booster vaccinations and enhanced surveillance in high-risk areas to prevent reinfection.

Cholera responses

Cholera response interventions are intended to reduce mortality and prevent disease transmission by integrating case management, water, sanitation and hygiene measures, vaccination, community engagement and surveillance.^{11,29} The cholera response model for the Democratic Republic of the Congo added case-area targeted interventions to the interventions used in the Yemen cholera response model to address the unique local context.^{29,30} Fig. 2 illustrates how these interventions were integrated into the susceptible–infected–recovered–susceptible framework. Box 1 summarizes the interventions included in the model (detailed descriptions are available in the online repository).²³

With anticipatory action, cholera outbreaks are mitigated proactively by mobilizing resources and implementing preventive measures before severe cases emerge.^{9,10} The activation threshold for anticipatory action was set by the United Nations Office for the Coordination of Humanitarian Affairs at 15 cholera cases per day (based on real-time surveillance data or reported case counts) and exceeding this threshold triggers the release of rapid action funds for intervention implementation.³⁶ In our study, all interventions listed in Box 1 were regarded as being implemented once anticipatory action is triggered. This approach emphasizes preparedness and the efficient allocation of resources to minimize the impact of cholera on the affected population.^{8,37}

Model validation

Validation of our system dynamics model followed Barlas's and Forrester & Senge's guidelines,^{38,39} and included direct structure tests, behaviour tests and reproduction tests.^{38,40} A local sensitivity analysis, which involved varying parameters by plus or minus 15% over 100 runs using the Sobol sequence sampling method,⁴¹ identified 10 key parameters that influenced the model (Table 1). In addition, a global sensitivity analysis, which involved 100 000 simulations, further explored the effect of varying parameters by 15% (this range is commonly used for system dynamics validation).^{38,42}

Fig. 3 compares historical data on the cholera infection rate in the Nyiragongo health zone during an outbreak between August 2022 and July 2024 with the corresponding projections of our cholera response model, including the results of a sensitivity analysis. Although the model's projections align with the historical trend, there are some discrepancies. For example, the sharp increases observed in the historical infection rate in December 2022 and November 2023 are not replicated in the model's projections, which reflects data inconsistencies and the exclusion of factors such as seasonality. Nonetheless, the model captures the dynamics of the cholera outbreak and the effect of the interventions, thereby enabling it to serve as a useful decision-support tool. The wide uncertainty intervals highlight the need for caution in interpreting the model's projections. Details of the validation process are provided in the online repository.²³

Results

We evaluated the effect of four intervention scenarios on the dynamics of cholera infection in a hypothetical health zone in the Democratic Republic of the Congo between January 2022 and January 2025: (i) scenario 1: baseline scenario corresponding to existing responses to a cholera outbreak; (ii) scenario 2: anticipatory action; (iii) scenario 3: anticipatory action plus one vaccine dose; and (iv) scenario 4: anticipatory action plus two vaccine doses. Table 2 summarizes the key features of these four scenarios, including differences in interventions, vaccination timelines and immunity periods.

Fig. 4 and Fig. 5 illustrate the effect of these four scenarios on the cholera infection rate in the hypothetical health zone projected by our cholera response model. Asymptomatic cases are included. In addition, Table 3 lists the estimated cumulative infected population (both symptomatic and asymptomatic) 3, 6 and 15 months after anticipatory action was triggered in October 2022. These time-points reflect operational benchmarks commonly used in outbreak evaluations by humanitarian organizations and highlight how the effect of the

interventions evolves from the short to the long term. Box-and-whisker plots illustrating the long-term impact of each scenario are available in the online repository.²³

Scenario 1

The baseline scenario models interventions that were implemented in the Nyiragongo health zone in 2022, excluding case-area targeted interventions, and serves as a reference point.

Fig. 4 shows that the number of infections rises consistently in this scenario to reach a peak in January 2023 when a vaccination campaign is launched to immunize 52% of the population of 540 000. This campaign markedly reduces cases by February 2023, which demonstrates that vaccination is effective in lowering disease transmission over the short-term. However, the immunity conferred by the single vaccine dose wanes after 6 months and vaccinated individuals become susceptible again. Combined with gaps in vaccination coverage and unaddressed structural challenges, the waning of immunity creates a pool of vulnerable individuals. Seasonal factors and complacency about hygiene practices contribute to a second wave of infections by late 2023, which illustrates the limitations of relying solely on reactive interventions.

Scenario 2

In this scenario, anticipatory action is triggered in October 2022 and interventions, such as case-area targeted interventions, the distribution of hygiene kits and latrine construction, are implemented immediately. These measures initially slow the spread of infection, which results in 24% (95% uncertainty interval, UI: 16–35) fewer infected individuals in January 2023, 3 months after anticipatory action was triggered, compared with the baseline scenario (Table 3). Despite this short-term success, infections peak again in January 2023 following cessation of the immediate interventions in December 2022 (Fig. 4). A subsequent vaccination campaign results in a temporary decline in the infection rate, mirroring the effect of a similar campaign in the baseline scenario. By late 2023, however, the absence of sustained measures leads to a resurgence in infections driven by the high number of susceptible individuals. This scenario highlights the vital need for sustained public health strategies to maintain infection control, such as ongoing hygiene education and booster vaccinations.

Scenario 3

Scenario 3 features immediate interventions combined with early vaccination. As in scenario 2, anticipatory action triggered in October 2022 curbs the infection rate, which peaks

in December 2022 before a rapid decline driven by early vaccine administration in late December (Fig. 4). By April 2023, 6 months after anticipatory action is triggered, there are 36% (95% UI: 25–51) fewer infected individuals than in the baseline scenario (Table 3), which demonstrates the efficacy of these combined strategies. However, the 6-month immunity period associated with the single vaccine dose results in a pronounced second wave, which peaks in November 2023. This resurgence in infection reflects immunity debt, which occurs when effective early vaccination enables people to avoid infection but limits the development of natural immunity. As the protection offered by the vaccine declines over time, a large portion of the population remains susceptible to infection. This scenario underscores the importance of complementary strategies, including booster doses, for sustaining long-term infection control.

Scenario 4

In scenario 4, anticipatory action interventions are supplemented by a two-vaccine-dose strategy, with the second dose administered at least 7 days after the first. Our cholera response model assumes that 280 000 vaccine doses are used, as in scenario 3. However, the two-dose regimen results in a reduction in coverage to 26%, which limits the impact of vaccination on disease transmission, with infections initially peaking in January 2023 (Fig. 4). Nevertheless, the 3-year immunity period associated with two vaccine doses prevents a second wave of infection, which distinguishes this scenario from the other three. By January 2024, 15 months after anticipatory action is triggered, there are 9% (95% UI: 7–13) fewer infected individuals than in the baseline scenario (Table 3). Moreover, the cumulative total number of infected individuals over the long term is the lowest among all scenarios (Fig. 5). This result shows that there is a trade-off between vaccine coverage and immunity duration and that strategic planning is important for maximizing the impact of vaccination in low-resource settings.

Discussion

Our study used a modification of a published cholera response model to explore the effectiveness of anticipatory action against cholera outbreaks in a hypothetical health zone in the Democratic Republic of the Congo.¹⁶ Overall, we found that combining immediate and long-term interventions optimized disease outcomes, that booster vaccine doses are essential and that our cholera response model can serve as an aid to decision-making.

First, our analysis indicates that immediate interventions provide a critical foundation for long-term strategies, such as vaccination. Our cholera response model projected that triggering anticipatory action in October 2022 was associated with 24% fewer infected individuals at 3 months compared with the baseline scenario, which corresponds to around 35 000 fewer infections. This finding aligns with published studies,^{29,43} which highlighted the importance of rapid response measures for reducing transmission at the onset of outbreaks. However, a subsequent resurgence in infections was projected when only triggering anticipatory action, which underscores the limitations of standalone immediate interventions. This observation mirrors previous conclusion that sustained measures were needed to prevent new waves of infection.⁴⁴ When we integrated immediate actions with a vaccination campaign, the projected number of infected individuals at 6 months was 64% of that in the baseline scenario. This synergistic effect demonstrates that immediate interventions can buy time for vaccination, thereby enhancing control efforts and extending their impact. Correspondingly, the Yemen cholera response model projected that starting interventions, particularly vaccination, sooner could avert 40% of deaths.¹⁶

Second, our analysis indicates that, to be effective, a single-vaccine-dose strategy in a resource-constrained context requires a subsequent booster dose. Our comparison of one-dose and two-dose vaccination strategies revealed an important trade-off. In scenario 3, the broad vaccine coverage achieved with a single dose is associated with 36% fewer infected individuals at 6 months than in the baseline scenario. However, waning immunity after 6 months leads to a resurgence in infections, which highlights the phenomenon of immunity debt. Consequently, as concluded by others, booster campaigns are important for sustaining immunity.^{13,45}

In our analysis, the projected cumulative number of people infected by January 2025 was approximately 30% lower when immediate interventions were combined with a two-vaccine-dose strategy, than with either the baseline scenario, scenario 2 or scenario 3. Despite this benefit, the lower vaccine coverage in scenario 4 means that 74% of people would not be covered, thereby leaving a larger proportion of the population susceptible to infection. This observation underscores the challenge of balancing immunity duration and vaccination coverage in resource-constrained settings. Findings from published studies suggest that single-dose vaccination campaigns may be more effective during outbreaks when vaccine supplies are limited.^{45,46} Nevertheless, long-term protection requires strategic planning for booster doses.

Third, in addition to its role in evaluating interventions, our cholera response model can serve as a dynamic platform for decision-making. By simulating outbreak scenarios, the model enables policy-makers to evaluate intervention strategies in a risk-free environment and to conduct real-time adjustments based on the model's projections. Other researchers have also found that interactive simulations were valuable for public health planning.^{47,48}

We found that water, sanitation and hygiene interventions play a crucial role in the management of cholera outbreaks over the long term. Emergency measures, such as fixed chlorination points, offer immediate benefits but coverage may be limited, as observed in Malawi and Yemen.^{26,49} The Global Task Force on Cholera Control's 2030 roadmap stresses that long-term investment in water and sanitation infrastructure is essential to progress from emergency responses to sustainable public health.¹¹ Although our focus was on medium-term interventions, our findings underscore the need for comprehensive improvements in water, sanitation and hygiene services alongside vaccination and immediate actions in response to disease outbreaks.

The results of our model indicate that triggering predefined anticipatory action during cholera outbreaks can improve outcomes compared with conventional outbreak declarations that occur weeks later. Health authorities are thus provided with a practical strategy for acting earlier, which could accelerate the release of funding and the roll-out of interventions. In settings such as North Kivu, this could translate into earlier vaccination (i.e. November 2022 rather than mid-January 2023 in our baseline scenario) and the faster deployment of hygiene measures and case-area targeted interventions – actions that national ministries, humanitarian organizations and their partners could adopt immediately if thresholds for anticipatory action were embedded in existing surveillance protocols.

To simplify the analysis, our cholera response model did not consider population displacement, conflict or seasonal factors but focused instead on broader population dynamics. Consequently, key drivers of cholera among refugee and internally displaced persons were omitted. Future work should include these drivers and stratify the population by age and gender. Moreover, as the ranges of some key parameters were hypothetical, it is important that these ranges are continuously calibrated with field data on the performance of interventions and with updated epidemiological information to strengthen confidence in the model's projections. Applying the model to other cholera hotspots will require adaptations to region-specific circumstances and iterative validation in partnership with local stakeholders

so that differences in water, sanitation and hygiene infrastructure, health-care capacity and security constraints are considered.

In conclusion, our study demonstrates that anticipatory action can enhance cholera outbreak management in low-resource settings, such as the Democratic Republic of the Congo, by combining immediate interventions with vaccination. Triggers for early anticipatory action that initiate interventions weeks before traditional outbreak declarations can buy critical time for deploying vaccines and for implementing other disease control measures, thereby reducing the risk of immunity debt and subsequent waves of infection. Our adapted cholera response model can serve as a dynamic learning platform that enables decision-makers to simulate and refine intervention strategies in a risk-free environment, thus supporting a shift from reactive to proactive planning in line with the 2030 Global Task Force on Cholera Control's roadmap. Future work on the model should explore its application to other regions with a high burden of disease, the use of real-world data for calibration and validation, and the incorporation of contextual factors such as population displacement. Ongoing refinement will strengthen the model's utility as a tool for public health decision-making and global efforts to control and eliminate cholera.

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Competing Interests:

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Box 1. Cholera response interventions, modelling study of the effect of anticipatory action on cholera outbreaks in the Democratic Republic of the Congo

Fixed chlorination points for clean water

Chlorination points at community water sources to ensure drinking water is safe – an interim solution to reduce waterborne bacterial transmission⁶

Hygiene kits

Soap, oral rehydration salts and water purification tablets to address immediate household needs during cholera outbreaks³¹

Latrine construction

Sanitary latrines to prevent faecal contamination of water sources, thereby reducing the spread of cholera³²

Cholera treatment centres

Inpatient facilities for severe cases, with sewage treatment systems to prevent environmental contamination³

Oral rehydration corners

Oral rehydration facilities at community-based clinics to prevent dehydration and reduce hospital admissions³³

Vaccination

Oral cholera vaccine offering up to 70% protection after two doses and suitable for mass campaigns during outbreaks^{34,35}

Surveillance system

Data on cholera cases collected from health centres to monitor the progression of the outbreak and guide response efforts⁷

Case-area targeted interventions

Rapid localized responses targeting areas within 100 to 250 m of a confirmed cholera case; responses may include water purification, sanitation measures, household visits, health education and active case-finding to quickly interrupt transmission in high-risk locations^{29,30}

Table 1. Key parameters influencing the cholera response model, modelling study of the effect of anticipatory action on cholera outbreaks in the Democratic Republic of the Congo

Parameter ^a	Range for sensitivity analysis	Sensitivity ^b
Average duration of symptomatic illness, days	13.03–15.93	Numerical
Average incubation time, days	4.36–5.33	Numerical
Bacterial shedding from asymptomatic infected individuals, CFUs/person	81.62–99.76 × 10 ³	Numerical
Bacterial shedding from mildly infected individuals, CFUs/person	8.551–10.45 × 10 ⁶	Numerical
Bacterial shedding from severely infected individuals, CFUs/person	29.65–36.24 × 10 ⁶	Numerical
Contact rate with contaminated water, contacts/person per day	9.01–11.01	Numerical
Proportion of severely infected individuals seeking care	0.61–0.75	Numerical
No. individuals with severe cholera at time zero	1–3	Numerical
Time to contaminate water, ^c days	17.17–20.98	Numerical
Disease transmission probability	0.05–0.06	Numerical

CFU: colony forming unit.

^a Parameters with the greatest influence on the cholera response model were identified in a sensitivity analysis, in which their values were varied by ± 15%.

^b Numerical sensitivity means that a variation in the parameter changes the magnitude of the model's results (e.g. the number of cases) but does not alter the fundamental system behaviour.

^c The time to contaminate water is the assumed delay between the time when infected individuals shed *Vibrio cholerae* into the environment and the time when the pathogen reaches and meaningfully contaminates the water source (details are available in the data repository).²³

Table 2. Intervention scenarios simulated using the cholera response model, modelling study of the effect of anticipatory action on cholera outbreaks in the Democratic Republic of the Congo

Scenario	Trigger for action	Interventions	Start of vaccination	Vaccination characteristics	Immunity period	Purpose
Scenario 1: baseline	Government outbreak declaration on 14 December 2022	All interventions in Box 1, excluding case-area targeted interventions	Mid-January 2023	280 000 doses delivered and 52% population coverage	6 months after single vaccine dose	To serve as a reference for other scenarios
Scenario 2: anticipatory action	Simulated case count reaches 15 per day on 25 October 2022	All interventions in Box 1	Mid-January 2023	280 000 doses delivered and 52% population coverage	6 months after single vaccine dose	To evaluate the impact of the early activation of interventions
Scenario 3: anticipatory action plus one vaccine dose	Simulated case count reaches 15 per day on 25 October 2022	All interventions in Box 1	One month after anticipatory action is triggered (i.e. November 2022)	280 000 doses delivered and 52% population coverage	6 months after single vaccine dose	To evaluate the combined impact of the early activation of interventions and a single vaccine dose
Scenario 4: anticipatory action plus two vaccine doses	Simulated case count reaches 15 per day on 25 October 2022	All interventions in Box 1	One month after anticipatory action is triggered (i.e. November 2022) ^a	280 000 doses delivered to 140 000 individuals and 26% population coverage	3 years after two vaccine doses	To evaluate the trade-off between the extended immunity provided by two vaccine doses and reduced vaccination coverage

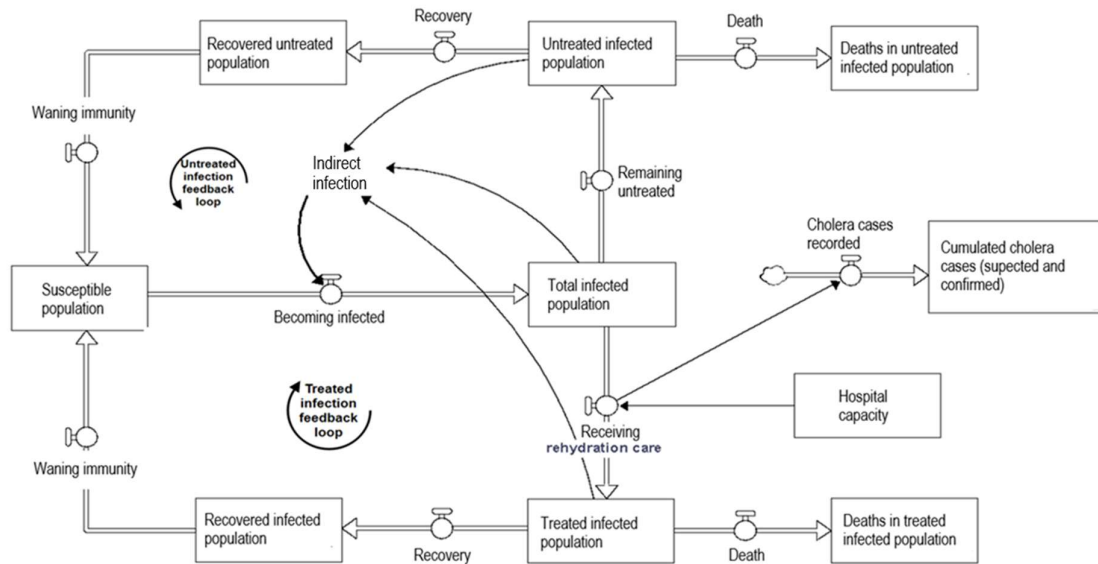
^a The second vaccine dose was administered at least 7 days after the first.

Table 3. Total infected population projected by the cholera response model, by time and intervention scenario, modelling study of the effect of anticipatory action on cholera outbreaks in the Democratic Republic of the Congo

Scenario	Total infected population ^a					
	Time after anticipatory action was triggered in October 2022					
	3 months (January 2023)		6 months (April 2023)		15 months (January 2024)	
	Cumulative no.	Difference from baseline, %	Cumulative no.	Difference from baseline ¹ , %	Cumulative no.	Difference from baseline 1, %
Scenario 1: baseline	141 417	Reference	266 349	Reference	500 513	Reference
Scenario 2: anticipatory action	106 988	–24	192 832	–28	490 222	–2
Scenario 3: anticipatory action plus one vaccine dose	100 649	–29	171 119	–36	508 134	2
Scenario 4: anticipatory action plus two vaccine doses	105 192	–26	222 396	–17	455 617	–9

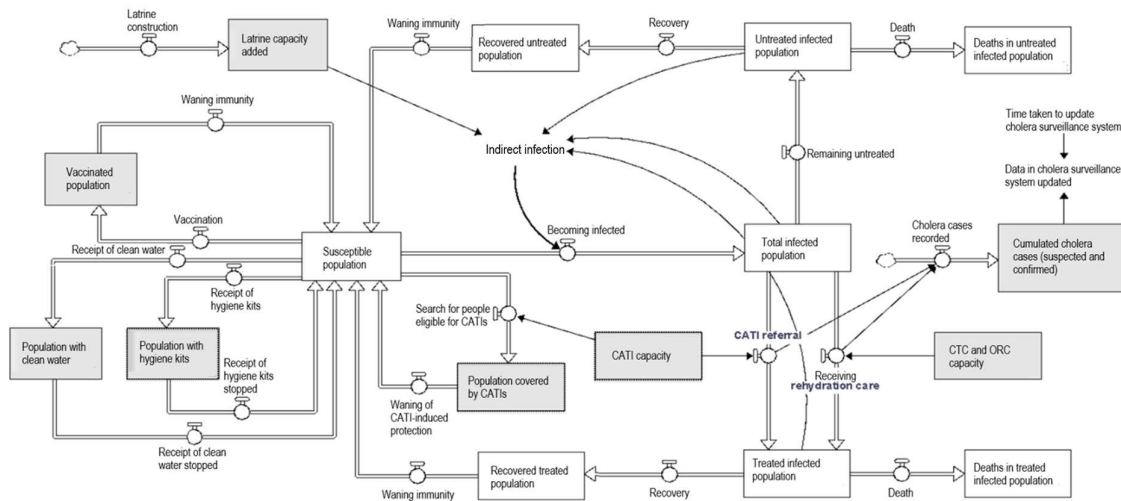
^a The total infected population includes both symptomatic and asymptomatic cases.

Fig. 1. Simplified diagram of infection processes and interventions in the cholera response model before declaration of a cholera outbreak, modelling study of the effect of anticipatory action on cholera outbreaks in the Democratic Republic of the Congo



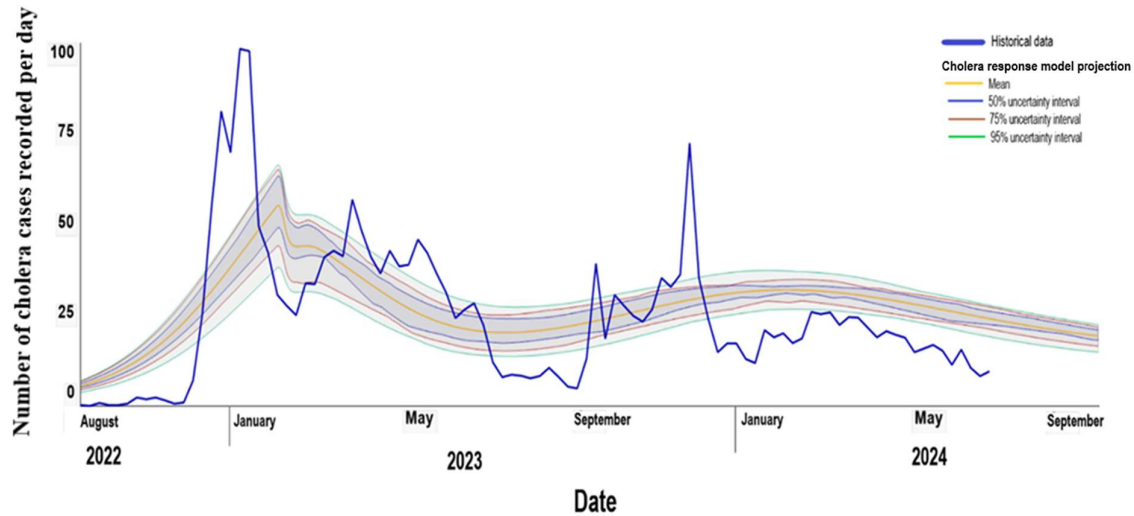
Notes: The cholera response model was based on a system dynamics model devised using data from a published model for Yemen.¹⁶ Indirect infection refers to the spread of cholera to susceptible individuals through contact with water that has been contaminated by individuals who are already infected.

Fig. 2. Simplified diagram of infection processes and interventions in the full cholera response model, modelling study of the effect of anticipatory action on cholera outbreaks in the Democratic Republic of the Congo



Notes: The cholera response model was based on a system dynamics model devised using data from a published model for Yemen.¹⁶ Indirect infection refers to the spread of cholera to susceptible individuals through contact with water that has been contaminated by individuals who are already infected. Oral rehydration corners were provided at community clinics.

Fig. 3. Comparison of historical cholera infection data and cholera response model projections, modelling study of the effect of anticipatory action on cholera outbreaks in the Democratic Republic of the Congo, August 2022 to September 2024



UI: uncertainty interval.

Notes: we obtained historical cholera infection data for an outbreak between August 2022 and July 2024 in Nyiragongo, Democratic Republic of the Congo. The cholera response model was based on a system dynamics model devised using data from a published model for Yemen.¹⁶

Fig. 4. Daily cholera infection rates projected by the cholera response model for four intervention scenarios, study of the effect of anticipatory action on cholera outbreaks in the Democratic Republic of the Congo, July 2022 to January 2025

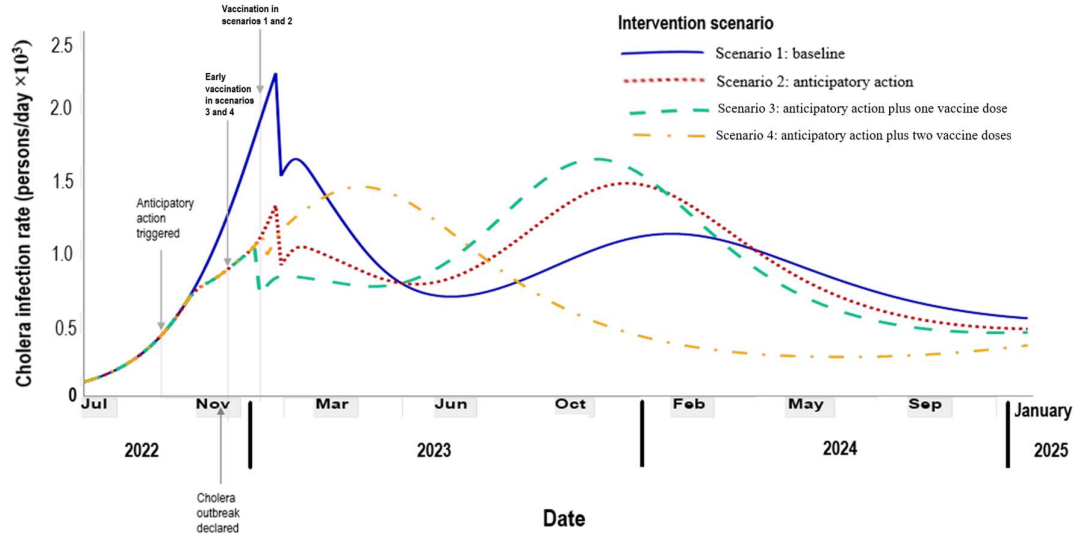


Fig. 5. Cumulative cholera infections projected by the cholera response model for four intervention scenarios, study of the effect of anticipatory action on cholera outbreaks in the Democratic Republic of the Congo, July 2022 to January 2025

