Description of the targeted WASH response strategy implemented during the cholera outbreak of 2017-2018 in Kinshasa, DRC

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Abstract

Background Rapid control of cholera outbreaks is a significant challenge in overpopulated urban settings, and documented results on field interventions are scarce. During the 2017-2018 period, Kinshasa, the capital ofDemocratic Republic of the Congo, experienced a sharp increase in cholera cases that showed potential to quickly spread throughout the city. A novel targeted WASH (Water, Sanitation and Hygiene) strategy was implemented to quickly stem the cholera outbreak. Methods We carried out a descriptive study of the cholera outbreak in Kinshasa from 2017 to 2018. Cholera surveillance databases from the Ministry of Health were analyzed to assess the spatiotemporal dynamics of the cholera outbreak using epidemic curves and cartography. Weekly precipitation levels in Kinshasa were also assessed. We also described the targeted cluster grid WASH strategy, which was implemented to quickly target case clusters at the household and community level, carrying out interventions focused on emergency water supply, household water treatment and safe storage, home disinfection and hygiene promotion. We also examined the evolution of the outbreak following implementation of the response strategy. Results From January 2017 to November 2018, a total of 1,712 suspected cholera cases were reported in Kinshasa. During this period, the health zones most affected included Binza Météo, Limeté, Kokolo, Kintambo and Kingabwa. Following implementation of the response strategy, the weekly cholera case numbers in Binza Météo, Kintambo and Limeté decreased by an average of 57% in two weeks and 86% in four weeks. The total weekly case numbers throughout Kinshasa Province dropped by 71% at four weeks after the outbreak peak. Conclusion During the 2017-2018 period, Kinshasa experienced a sharp increase in cholera cases that showed potential to quickly spread throughout the city. To contain the outbreak, WASH response interventions targeted case households, nearby neighbors and public areas in case clusters using a grid approach. Following implementation of the WASH response, the outbreak in Kinshasa was quickly brought under control. A similar approach may be useful to quickly interrupt cholera transmission in other urban settings.

Background

Cholera is an acute diarrheal disease caused by consumption of water or food contaminated with toxigenic forms of *Vibrio cholerae* (1). Once an individual contracts cholera, subsequent disease transmission is associated with limited access to clean drinking water and poor sanitation conditions (1,2). The disease continues to represent a global public health concern, especially in Sub-Saharan Africa.

To stem this public health threat, Global Task Force for Cholera Control (GTFCC) partners endorsed a call to action in 2017 via implementation of the "Ending Cholera – A Global Roadmap to 2030" (3,4). The Ending Cholera Roadmap aims to stop cholera epidemics in up to 20 countries and reduce cholera-related deaths by 90% by the year 2030 (4). The first main axis of the multisectoral approach involves early detection and quick response to contain outbreaks. However, rapid control of cholera outbreaks can be a significant challenge in urban settings, as cholera case numbers can quickly increase, especially in overpopulated areas with poor sanitation (2,5). Once cholera outbreaks expand in urban areas, cholera has often eventually spread to linked regions within the country or across international borders associated with the travel and migration of at-risk populations (6–8). As a result, effective strategies to control cholera outbreaks in urban settings may play a major role in controlling cholera epidemics on a local, national and regional scale.

Over the past two decades, the Democratic Republic of the Congo (DRC) has borne a significant proportion of the global cholera burden. Between 2010 and 2017, the DRC reported approximately 220,000 suspected cholera cases, accounting for 25% of all cholera cases notified in Africa (9). Cholera is considered endemic in the African Great Lakes region of eastern DRC, where cholera cases have been consistently reported over the past two decades (10,11). By contrast, cholera outbreaks have only intermittently occurred in the western DRC provinces, including the national capital Kinshasa (11–13). Although Kinshasa has only been sporadically affected by the disease, the city remains vulnerable to outbreaks. In 2011, an epidemic spread outside of the cholera-endemic zone in eastern DRC and along the Congo River towards Kinshasa Province (13,14). The cholera outbreak quickly spread throughout Kinshasa (10) and continued for 116 weeks, well into 2013, resulting in 2,144 cases (case fatality rate (CFR) 2.3%) (13).

In recent years, cholera case numbers have significantly increased in DRC (9,11). The epidemic of 2017 represented the largest cholera epidemic to affect the country since 1994, with approximately 56,000 cholera cases reported nationwide (9). During this time, cholera outbreaks again spread outside of the cholera-endemic zone in eastern DRC and into western provinces, including Kinshasa. Between April 2016 and March 2018, Kinshasa experienced three cholera outbreaks of increasing intensity, with weekly case numbers peaking in December of 2017.

In this study, we analyzed the spatiotemporal evolution of the cholera outbreaks in Kinshasa from January 2017 to November 2018. We also describe the targeted WASH response strategy designed to stop cholera transmission in heavily-affected health zones, which focused on improved access to potable water, household disinfection and hygiene promotion (15).

Methods

Study design and site

We performed a descriptive study of the cholera outbreak in Kinshasa during the 2017-2018 period covering all administrative health zones of Kinshasa Province. We also describe the targeted cluster grid WASH strategy and assess the impact of this approach to interrupt cholera transmission. Kinshasa Province is one of 26 provinces in DRC and is coterminous with the national capital. The city-province is divided into 35 administrative health zones. Kinshasa is located in the far west of the country on the banks of the Congo River (Figure 1). The province covers approximately 9,965 km^2, with an estimated population of nearly 12 million. Infrastructure measures have not kept pace with urbanization and the increasing population in the city (16). As a result, neighborhoods have been established in flood-prone areas where water drainage is a challenge, thus increasing the risk and severity of flooding, especially during heavy rains in November and April (17).

Figure 1. Map of study area: Kinshasa Province. DRC, Democratic Republic of the Congo.

Surveillance data sources

The National Integrated Disease Surveillance and Response System was established in 2000 by the DRC Ministry of Health in conjunction with the World Health Organization (WHO). The Integrated Disease Surveillance and Response System targets thirteen infectious diseases with epidemic potential, including cholera, for passive surveillance (18). In each cholera treatment center (CTC), suspected cases and deaths due to moderate and severe cholera infection are documented via line list (19), which includes the patient's address, age, sex, date of admission, date of onset, travel history during 14 days prior to symptom onset, and observation of any other individual in the case household with diarrhea. Trained Ministry of Health officials aggregate and anonymized these data at the health zone level and report the data to the Ministry of Health in Kinshasa every week.

Cholera case definition

According to WHO policy, a suspected case of cholera is defined as "any person two years of age or older in whom acute watery diarrhea with or without vomiting develops" during a cholera outbreak (20). The age limit is increased to five years or older in interepidemic periods to reduce the number of false positives. At the beginning of an outbreak, between five and ten stool samples from each health zone are laboratory confirmed through isolation of *Vibrio cholerae* in culture. Subsequent cases of acute watery diarrhea in the same geographic region are presumed to be cholera.

Epidemiological data management and analyses

Secondary data was extracted from surveillance databases organized by staff of the National Program for Cholera Elimination and Diarrheal Disease Control (Programme National d'Elimination du Choléra et de lutte contre les Maladies Diarrhéiques [PNECHOL-MD]). Quality verification of the database was conducted, in which data was verified for consistency and analyzed to determine weekly case numbers per health zone using Microsoft Excel. Epidemic curves per health zone were drawn to assess the temporal evolution of the outbreak in Kinshasa as well as outbreaks in each affected health zone, covering the period week 1 of 2017 to week 45 of 2018 (the epidemic curve shows cases starting from week 15 of 2017, as only limited cases were reported earlier in the year). Total weekly case and death numbers per health zone were also used to perform a descriptive analysis of the outbreak as well as impact following implementation of the WASH response strategy. All suspected cholera cases reported in each health zone from November 1st 2017 to March 31st 2018 was used to represent the geographic distribution of cholera cases during the main outbreak period shown in Figure 4.

Cartography

The maps of Kinshasa and DRC were generated using QGIS V3.4.3 Madeira with shapefiles provided by the DRC Ministry of Health (DRC health zones, DRC provinces, rivers and lakes). Additionally, shapefiles of Republic of the Congo administrative boundaries and

transportation network features (rail and road) were retrieved from DIVA-GIS (http://www.diva-gis.org/gdata). The GPS coordinates of the CTCs were provided by the Kinshasa Ministry of Health for localization in the map.

Precipitation data

Precipitation levels were derived from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) dataset (product: Daily UCSB CHIRPS v2p0 daily-improved global 0p25). The CHIRPS precipitation data is a 30-year quasi-global rainfall dataset supported by University of California Santa Barbara (CA, USA). Daily values were extracted and aggregated by health zone (R environment for statistical computing and graphics). Spatial aggregation from gridded data at the province level for Kinshasa was carried out in R. Daily precipitation levels (mm) were then aggregated by week using Microsoft Excel.

Field visits

Field visits were conducted by joint investigation teams composed of representatives of the PNECHOL-MD, Provincial Health Directorates and community agents in each affected health zone. Investigation teams met with local surveillance departments and health facilities. Information was collected concerning potential sources of infection, possible links between cases and risk factors (19). In each case cluster area, the investigation teams also evaluated local demographic data, WASH indicators and other factors that may play a role in cholera dynamics (21):

- Local demographic data (number of people per household, occupation and place of work of adults in the household).
- Factors contributing to amplification or persistence of an outbreak: high population density, potentially contaminated sources of drinking water and poor water quality, poor sanitation (open defecation, broken sewer pipes, etc.), poor food hygiene, crowded or high-risk gathering places (markets, transportation hubs, schools, surface water bathing sites, etc.), and current meteorological conditions.

Description of the WASH response using the cluster grid targeted approach

The main objective of the cluster grid WASH strategy was to quickly target case clusters (including affected households and at-risk populations in the community), carrying out interventions focused on emergency water supply, household water treatment and safe storage, home disinfection and hygiene promotion (15,21–24), as described in detail below.

To inform and guide the targeted WASH response, the epidemiological data was analyzed to identify the most affected health zones (reporting more than 10% of the total suspected cholera cases during the previous three weeks). Subsequently, each new affected health zone that experienced a lab-confirmed outbreak, for which risk factors that may trigger an increase in cases according to field investigations, was included in the grid approach once the outbreak was laboratory-confirmed. As a result, five health zones (Binza Météo, Limeté, Kintambo, Kingabwa and Bumbu) were selected for targeted WASH interventions. During the response, daily case admission trends, including origin of patients, were monitored to assess the epidemiological evolution of the outbreak in real time and adjust response activities accordingly.

To target case clusters within each of the five health zones, the line lists of suspect cases were consulted in the registers of the two CTCs to obtain the address of patients admitted over the last 14 days (CTCs were established in Limeté (Pakadjuma) and Binza Météo (the shantytown of Camp Luka)).

were identified. A response team then visited the patient residences to GPS-localize the case households. The households from which the most recent cases originated (<14 days) were mapped, and a circle (500-meter radius) was delineated around each cluster, which was then subdivided into a grid. Each grid unit representing an average of 20-30 households, which varied depending on the geographical characteristics of the area (Figure 2).

Figure 2. Schematic diagram of targeted cluster grid WASH strategy at the household and community level. The case cluster is shown in green, case households are represented by red dots, nearby neighbors (<50 m from a case household) are represented in red squares and peripheral neighbors (>50 m from a case household, within the case cluster) are represented in orange squares.

To reduce cholera transmission within the case clusters, the appropriate WASH interventions were applied depending on the transmission context (e.g., case households, public places in the community) (25).

The following WASH activities were carried out at case households and the 20 contiguous households (≤50 m from a case household) within case clusters:

- Chlorine-based water purification tablets (sodium dichloroisocyanurate, 7 mg) were distributed for household water treatment, together with water treatment instructions (15).
- All types of household water sources were systematically chlorinated everyday over a 14-day period (e.g., water used for drinking, bathing and other household purposes), with either sodium dichloroisocyanurate or 1% concentration solution.
- Surfaces likely to be contaminated with vomit or diarrhea from cholera cases were disinfected with a 0.2% chlorine solution (22), within less than 72 hours after patient registration at the CTC.
- Each household was provided a household hygiene kits, containing soap, a 20-liter water storage container and ready-to-use chlorine (1% concentration solution) for disinfection of drinking water (23,24). Water storage containers were distributed together with instructions to safety store household drinking water (26).
- To enhance health awareness and encourage safe practices, hygiene and health messages were delivered together with the hygiene kits (21,22).

The following activities were carried out at-risk peripheral households (>50 m from a case household) within case clusters:

- Chlorine-based water purification tablets (sodium dichloroisocyanurate, 7 mg) were distributed for household water treatment, together with water treatment instructions (15).
- All types of household water sources were systematically chlorinated everyday over a 14-day period (e.g., water used for drinking, bathing and other household purposes), with either sodium dichloroisocyanurate or 1% concentration solution.
- Each household was provided a household hygiene kits, containing soap, a 20-liter water storage container and ready-to-use chlorine (1% concentration solution) for disinfection of drinking water (23,24). Water storage containers were distributed together with instructions to safety store household drinking water (26).
- To enhance health awareness and encourage safe practices, hygiene and health messages were delivered (21,22).

The activities carried out at public places in the community, within case clusters, over the course of 14 days are described below. Additional details concerning the WASH interventions in each health zone are displayed in Table 1.

- Water bladders (10-m^3) and fixed water chlorination points (bucket chlorination) were installed at public places (e.g., water points, markets, schools, healthcare facilities and transport stations). Water bladders were installed in neighborhoods of high population density without a source of safe drinking water nearby,Two water bladders were installed in Limeté in proximity to the CTC, where they also served to provide safe drinking water to the nearby population, and one water bladder was installed Kingabwa. refilled every 48 to 72 hours by national water company tankers (REGIDESO). Residual chlorine levels in bladder water was measured prior to distribution. Fixed chlorination points were installed only in the health zones most affected early during the outbreak: Binza Météo and Kintambo.
- Handwashing points were installed at public places in Binza Météo and Kintambo.
- Hygiene education messages were disseminated to the community to promote health-seeking behaviors and protection mechanisms via health promotion campaigns in public places (i.e., markets, schools, transport stations, water points). Messages were communicated via radio, TV, posters and town criers, and topics included the modes of transmission, water treatment, and the importance of reporting cases of severe diarrhea (15).
- Public health rules were enforced together with local health authorities - swimming in surface waters (e.g., lakes, rivers, streams) was banned during the 14-day period (28).

Table 1. Community-level intervention details per health zone.

Health zone	Details of WASH interventions at the community level			
	Intervention duration	*Number of water bladders*	*Number of fixed water chlorination points*	*Number of handwashing points*
Binza Météo	60 days	0	15	4
Limeté	30 days	2	0	0
Kintambo	30 days	0	2	3
Kingabwa	30 days	1	0	0
Bumbu	30 days	0	0	0

Field response teams consisted of a supervisor, two educators (a crier and a door-to-door educator), four chlorinators (two for fixed sites and two for door-to-door household visits), two disinfectors and two attendants at handwashing points. Each team covered at least two 30-household grid units. The number of personnel involved per intervention type in each health zone is detailed in Table 2.

Table 2. Number of personnel involved by intervention type for each health zone.

Health zone	Number of personnel by intervention type				
	Educators	*Chlorinators*	*Disinfectors*	*Supervisors*	*Total Personnel*
Binza Météo	135	60	42	20	257
Limeté	8	10	10	4	32
Kintambo	40	8	10	5	63
Kingabwa	18	17	10	5	50
Bumbu	40	40	30	8	118
Total	241	135	102	42	520

Additional response activities conducted in case clusters

In parallel to WASH activities, active case search was carried out in the community, prioritizing the immediate entourage of probable and confirmed cases identified or treated at the CTC (15). Chemoprophylaxis of all immediate contacts of cholera cases was also conducted during household visits to provide short-term protection against infection (29,30). Adults received a single dose of doxycycline (300 mg), while children and pregnant women received a single dose of ciprofloxacin (20-30 mg/kg).

Ethics

Ethics approval was not required for this study as cholera epidemic disease surveillance and response are covered by national public health laws as an integral part of the public health mandate of the DRC Ministry of Health

Results

Spatiotemporal assessment of the cholera outbreak in Kinshasa during the 2017-2018 period

In the context of the largest cholera epidemic in the DRC since 1994, a total of 1,712 suspected cholera cases and 53 deaths (CFR 3.1%) were reported in Kinshasa from week 1 of 2017 to week 45 of 2018. *Vibrio cholerae* O1 Inaba was identified as the responsible agent. During this period, the first outbreak in Kinshasa occurred from mid-May to late-August 2017 and remained primarily confined to a Military Camp in Kokolo (Figure 3), a closed environment with very high population density (220 cases, CFR 6.4%).

The second and main outbreak began on November 25, 2017 (31). This outbreak spread quickly throughout Kinshasa, with cases first reported in densely inhabited Camp Luka in Binza Météo Health zone (red line in the epidemic curve), followed by Limeté during the last week of 2017 (orange line), and Kintambo during early-January 2018 (light green line) (Figure 3).

Figure 3. Epidemic curve of the cholera outbreaks in Kinshasa and corresponding weekly precipitation levels. The epidemic curve and weekly precipitation levels covers the period week 15 of 2017 to week 45 of 2018. The top panel displays weekly cholera case numbers in the entire city (dashed line) as well as heavily-affected health zones, which are color-coded and ordered based on cumulative

number of cholera cases during 2017 and 2018 period (up to week 45, 2018) as displayed in Additional file 1. The bottom panel displays the corresponding estimated weekly precipitation levels in Kinshasa (mm).

The outbreak in Kinshasa peaked during the first two weeks of January 2018, when 188 and 189 suspected cases were reported per week, respectively. By the first week of January, cholera cases had rapidly spread throughout Kinshasa, affecting the health zones of Binza Météo, Kintambo, Bandalungua, Mont Ngafula II, Kokolo and Limeté. An outbreak was also reported in Bumbu during the second week of 2018 (purple line in Figure 3). Nine other health zones in the city reported cholera cases by mid-January, and an additional 11 health zones reported cholera cases by late-January.

During the main outbreak period, from November 2017 to March 2018 (week 45, 2017 - week 13, 2018), a total of 1,097 cholera cases and 11 cholera-related deaths were reported in Kinshasa. The majority of cases were concentrated in health zones in northwest Kinshasa, less than 10 km from the Congo River. During this period, Binza Météo Health zone reported 37% of all cases (405 cases), followed by Limeté (19%; 208 cases), Kintambo (12%; 134 cases), Kingabwa (6%; 69 cases), Kokolo (3%; 38 cases) and Bumbu (3%; 37 cases). Together, these six health zones reported 81% of all cholera cases in Kinshasa during the five-month period (Figure 4).

Figure 4. Total cholera case numbers per health zone in Kinshasa from November 2017 to March 2018. The red circles represent the number of cumulative cholera case numbers (suspected and confirmed) in each health zone during the five-month period. The only areas not represented on the map are the large health zones located in the east of Kinshasa Province, Maluku II and Maluku I, which reported seven and 21 cases, respectively, during the five-month period. Health zones, main roads, railroads and waterbodies in Kinshasa are indicated. The GPS coordinate-based localization of the CTCs in Binza Météo (Camp Luka) and Limeté (Pakadjuma) is also indicated. Neighboring Republic of the Congo is shown in green. Localization of Kinshasa Province (gray) and the Kinshasa map area (red square) are specified on the map of DRC in the lower right corner.

Reduction in case numbers following implementation of the targeted WASH strategy

The cluster grid strategy was first implemented in Camp Luka (Binza Météo) during the last week of 2017, when 116 weekly cases were reported. Binza Météo was the most affected area and the starting point of the outbreak. In Binza Météo, the weekly number of cases quickly dropped following strategy implementation, with less than five cases per week reported by early February. As the outbreak spread, the cluster grid WASH approach was then implemented in Kintambo during the first week of January, followed by Limeté in late-January and both Kingabwa and Bumbu in early-February. In both Kintambo and Limeté, implementation of the WASH response strategy also led to a rapid decrease in cholera cases. Both outbreaks were brought under control by mid- to late-February (Figure 5).

We assessed the weekly rate in reduction of cholera case numbers following implementation of the response strategy in the health zones experiencing the largest outbreaks: Binza Météo, Kintambo and Limeté. Two weeks after implementing the strategy, the weekly cholera case numbers decreased by 43%, 63% and 65%, respectively, compared to starting point weekly case numbers. Four weeks after strategy implementation, the weekly case numbers decreased by 85%, 98% and 75%, respectively. Eight weeks after strategy implementation, the weekly case numbers decreased by 100%, 100% and 98%, respectively. Considering all cholera cases reported in Kinshasa, the weekly case numbers dropped by 71% at four weeks after the outbreak peak and by 83% at eight weeks after the peak (Table 3). Kingabwa and Bumbu were not included in the health zone-specific analysis, as weekly cholera case numbers remained below 14 and four, respectively.

Figure 5. Cholera epidemic curve of targeted health zones and response activity timeframe. Weekly cholera case numbers are shown on the y-axis and epidemic weeks/years are indicated on the x-axis. The start and end points of the WaSH response activities in each health zone are shown with green and red arrows, respectively.

Table 3. Reduction in cholera case numbers following implementation of the WASH response.

	Strategy starting point	Reduction in number of cholera cases (%) compared to implementation week			
Health zone	**No. of weekly cases during week of strategy implementation**	**after one week**	**after two weeks**	**after four weeks**	**after eight weeks**
Binza Météo	116	20.7%	43.1%	84.5%	100%
Kintambo	54	5.6%	63%	98.1%	100%
Limeté	40	22.5%	65%	75%	97.5%
	No. weekly cases once strategy was implemented in two health zones				
Kinshasa Province Total	188	-0.5%	11.7%	70.7%	83%

Kingabwa and Bumbu were not included in the health zone-specific analysis, as weekly cholera case numbers remained below 14 and four, respectively, once the strategy was implemented.

Overall, the cluster grid WASH response was implemented in five health zones that accounted for 78% of cases reported in Kinshasa between November 2017 and March 2018. Response activities were initiated in the targeted health zones between one to four weeks after the first local cases were reported, and the outbreaks stabilized between three to seven weeks after intervention activities were initiated.

Discussion

In late November 2017, a cholera outbreak occurred in Kinshasa, DRC. The outbreak quickly spread throughout the city, affecting 31 of 35 health zones by early-February. The cluster grid WaSH strategy was implemented during the peak period to rapidly contain the outbreak by targeting five heavily-affected health zones in Kinshasa. This strategy targeted case clusters, at the household and community level, with interventions focused on emergency water supply, household water treatment and safe storage, home disinfection and hygiene promotion. Targeting of case households and nearby neighbors was organized using a cluster grid approach. Following implementation of the response strategy, the outbreak in Kinshasa was quickly brought under control. In the three health zones reporting the most cases – Binza Météo, Kintambo and Limeté – the weekly cholera case numbers dropped by an average of 57% by two weeks post-strategy implementation and 86% by four weeks post-strategy implementation. The total weekly case numbers throughout Kinshasa Province dropped by 71% at four weeks after the outbreak peak and by 83% at eight weeks after the peak.

Previous studies have shown that the risk of cholera infection is significantly higher for household contacts of cholera patients (32), especially during the week after the cholera case seeks treatment (33,34). As a result,

interventions targeting case households using a variety of response measures have been applied during cholera outbreaks, although little evidence has been published concerning the effectiveness, efficiency or optimal implementation strategy.

Furthermore, cholera risk in urban settings has been shown to increase among nearby neighbors of cholera cases during the initial five days following disease onset (35). The relative risk of infection during the first three days has been shown to be 36 times greater within a 50-meter radius of a confirmed case, six times greater within a 51- to 100-meter radius, and five times greater within a 101- to 150-meter radius (35,36). A recent micro-simulation model has highlighted the potential impact of case-area targeted interventions in response to cholera outbreaks (37). The study also found that early intervention was important to rapidly interrupt disease transmission (37). Response strategies targeting case households and nearby neighbors are especially critical in urban contexts due to the limited availability of resources for non-targeted approaches and explosive potential of outbreaks in overcrowded areas. To ensure a rapid response and quick reduction in cholera case numbers, early case detection, case confirmation and pre-positioning of WaSH and case management supplies are fundamental.

In addition to describing the package of WASH interventions carried out during the outbreak response, we also describe the use antibiotic prophylaxis of all immediate contacts of cholera cases. During the sharp increase in cases, the outbreak showed potential to spread rapidly throughout the city, and antibiotic prophylaxis was included among emergency control interventions to reduce short-term risk of infection. However, considering the potential risk of bacterial drug resistance, this measure is not recommended by the WHO (29), and we therefore do not aim to promote nor analyze this intervention in this study.

Some study limitations should be noted. First, as we assessed the overall evolution of the outbreak, before and after implementation of the targeted WASH strategy, we cannot establish the effect of the individual interventions in this report. Confounding effects of individual interventions are also difficult to demonstrate; for example, increasing the supply and quality of available water may also have an effect on improved household hygiene (38). Second, this study lacks a non-intervention control group because the response strategy was carried out in all health zones experiencing over 3% of cholera cases from November 2017 to March 2018 (with the exception of the closed environment Kokolo Military Camp), and non-intervention would pose major ethical concerns. Third, as this is the first implementation of the cluster grid WASH strategy, further studies are needed to fully ascertain the potential of this approach and refine strategy design. Additional studies should include household surveys to assess WaSH indicators and outcome indicators. A cross-sectional survey should be included to assess the improvements made following the strategy. Systematic molecular biology assessment of water samples should be included to determine the evolution in water quality. Over the course of the strategy, the field team should complete a structured questionnaire to better map the conditions of disease transmission.

Overall, our results demonstrate that cholera case numbers rapidly decreased throughout Kinshasa following implementation of the targeted WASH response strategy. Our findings provide valuable lessons from the field for actors and international donors involved in cholera control. To eventually eliminate cholera, it is important to establish long-term solutions to ensure a safe and sustainable drinking water supply and improved sanitation for the population (39–41). However, until potable water and proper sanitation can be ensured in a sustainable manner in at-risk areas, the cluster grid WASH strategy may be adapted and applied to quickly stop cholera transmission in other urban settings.

Conclusions

During the 2017-2018 period, Kinshasa experienced a sharp increase in cholera cases that showed potential to quickly spread throughout the city. The targeted cluster grid WASH strategy was developed and implemented to rapidly contain the outbreak. The response strategy targeted case clusters in five heavily-affected health zones, in which WASH activities at case households, nearby neighbors and public places in the community focused on emergency water supply, household water treatment and safe storage, home disinfection and hygiene promotion. Following implementation of the WASH response, the outbreak in Kinshasa was quickly brought under control. In health zones experiencing the largest outbreaks - Binza Météo, Kintambo and Limeté - the weekly cholera case numbers decreased on average by 57% two weeks post-strategy implementation and by 86% four weeks post-strategy implementation. With appropriate adaptations, a similar approach may be useful to quickly stop cholera transmission in other urban settings.

List Of Abbreviations

CFR	Case fatality rate
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station
CTC	Cholera treatment center
DRC	Democratic Republic of the Congo
WASH	Water, sanitation and hygiene
WHO	World Health Organization

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and material

The datasets analyzed during the current study are not publicly available, beyond the data supplied in the Additional file 1, due to data transfer agreements. However, the surveillance data may be available upon reasonable request with permission from the DRC Ministry of Health (contact email: pnecholmd01@gmail.com).

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

DB and TV designed the study. NT curated the surveillance data. DB, SM, NT, BS, BI, RM, FM, TV and TB analyzed and interpreted the data. SM produced and analyzed the epidemic curves and maps. BS performed the precipitation extraction and analysis. DB and NT performed field investigations. DB, NT and SM wrote the manuscript. DB, SM, BS and TV reviewed and edited the manuscript. All authors read and approved the final version of the manuscript.

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Figures

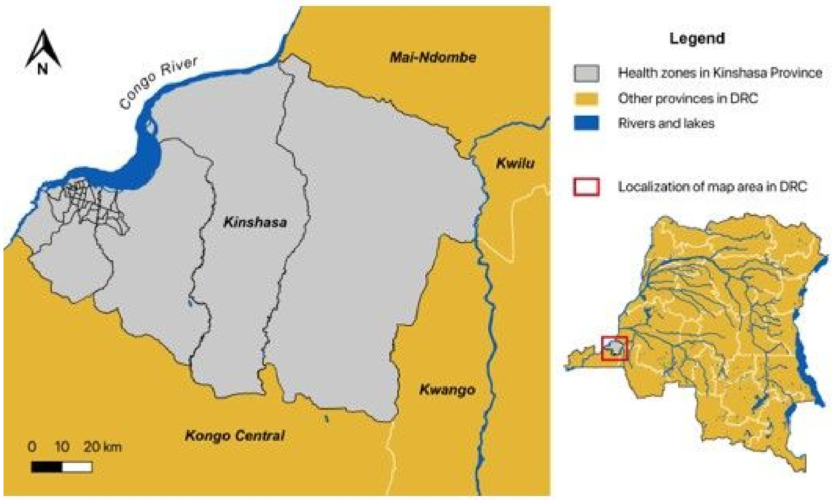

Figure 1

Map of study area: Kinshasa Province. DRC, Democratic Republic of the Congo.

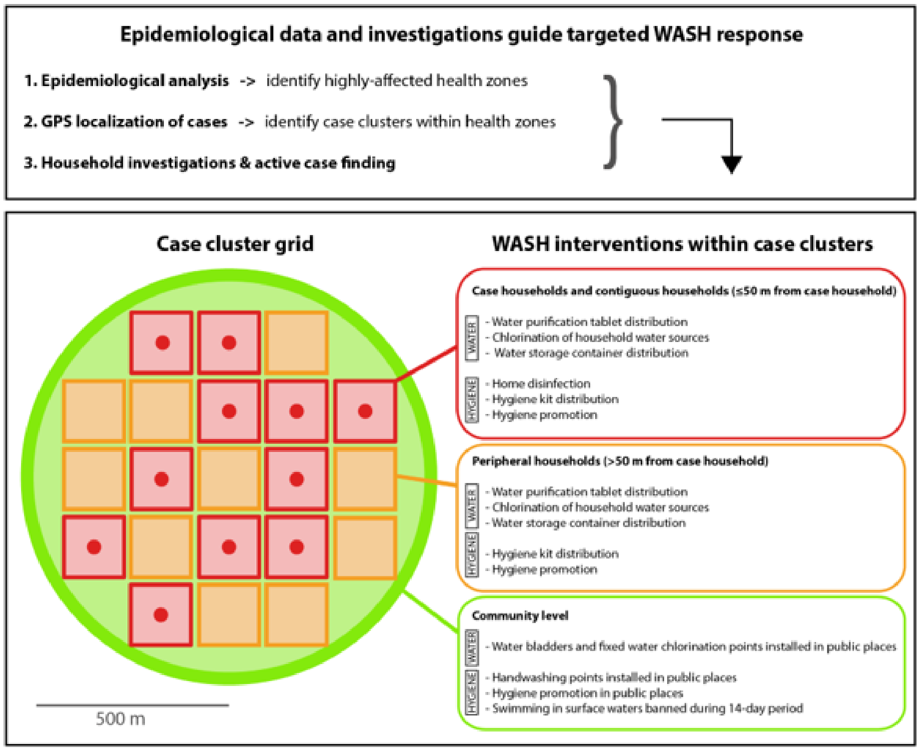

Figure 2

Schematic diagram of targeted cluster grid WASH strategy at the household and community level. The case cluster is shown in green, case households are represented by red dots, nearby neighbors (<50 m from a case household) are represented in red squares and peripheral neighbors (>50 m from a case household, within the case cluster) are represented in orange squares.

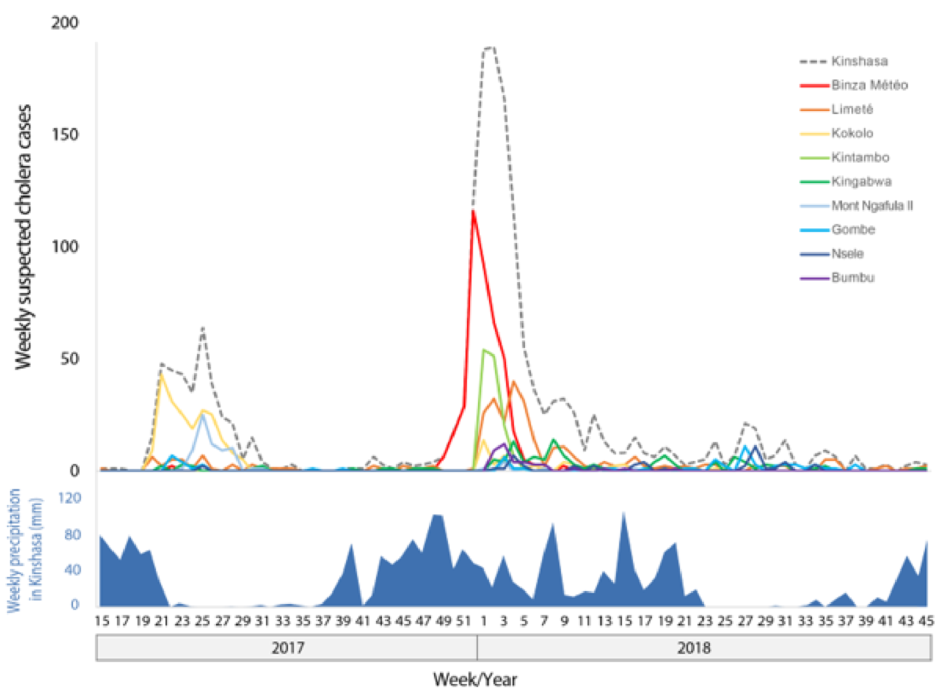

Figure 3

Epidemic curve of the cholera outbreaks in Kinshasa and corresponding weekly precipitation levels. The epidemic curve and weekly precipitation levels covers the period week 15 of 2017 to week 45 of 2018. The top panel displays weekly cholera case numbers in the entire city (dashed line) as well as heavily-affected health zones, which are color-coded and ordered based on cumulative number of

cholera cases during 2017 and 2018 period (up to week 45, 2018) as displayed in Additional file 1. The bottom panel displays the corresponding estimated weekly precipitation levels in Kinshasa (mm).

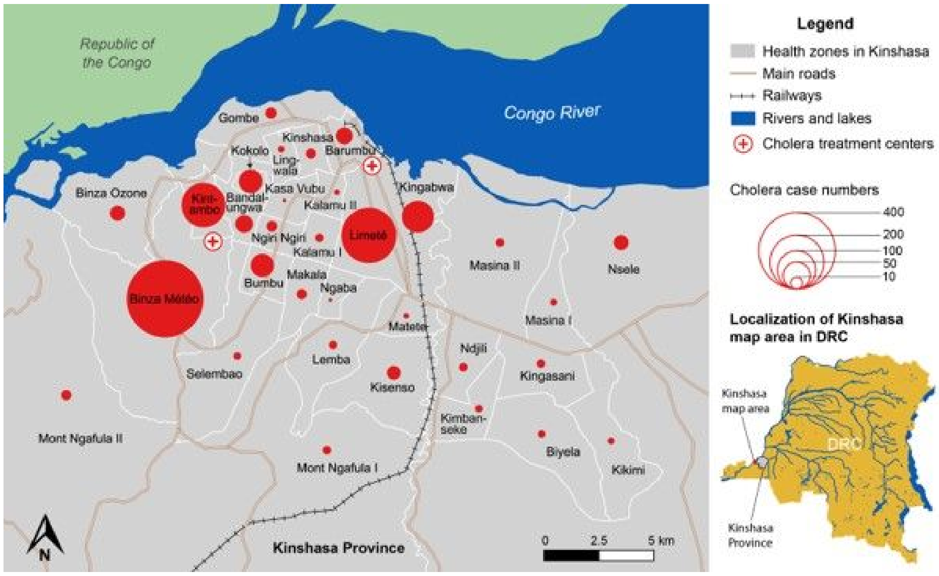

Figure 4

Total cholera case numbers per health zone in Kinshasa from November 2017 to March 2018. The red circles represent the number of cumulative cholera case numbers (suspected and confirmed) in each health zone during the five-month period. The only areas not represented on the map are the large health zones located in the east of Kinshasa Province, Maluku II and Maluku I, which reported seven and 21 cases, respectively, during the five-month epidemic period. Health zones, main roads, railroads and waterbodies in Kinshasa are indicated. The GPS coordinate-based localization of the CTCs in Binza Météo (Camp Luka) and Limeté (Pakadjuma) is also indicated. Neighboring Republic of the Congo is shown in green. Localization of Kinshasa Province (gray) and the Kinshasa map area (red square) are specified on the map of DRC in the lower right corner.

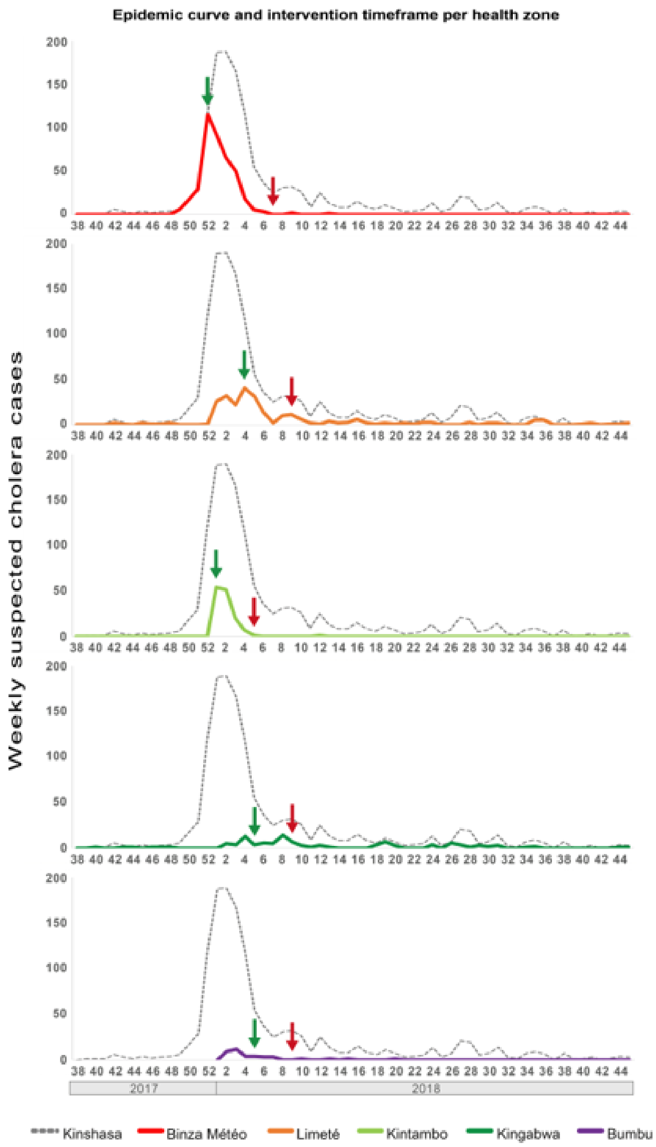

Figure 5

Cholera epidemic curve of targeted health zones and response activity timeframe. Weekly cholera case numbers are shown on the y-axis and epidemic weeks/years are indicated on the x-axis. The start and end points of the WaSH response activities in each health zone are shown with green and red arrows, respectively.

Supplementary Files

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- Additionalfiles.docx