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High-resolution spatial analysis of cholera patients reported in Artibonite department, Haiti in 2010–2011

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ABSTRACT

Background: Cholera is caused by *Vibrio cholerae*, and is transmitted through fecal-oral contact. Infection occurs after the ingestion of the bacteria and is usually asymptomatic. In a minority of cases, it causes acute diarrhea and vomiting, which can lead to potentially fatal severe dehydration, especially in the absence of appropriate medical care. Immunity occurs after infection and typically lasts 6–36 months.

Cholera is responsible for outbreaks in many African and Asian developing countries, and caused localised and episodic epidemics in South America until the early 1990s. Haiti, despite its low socioeconomic status and poor sanitation, had never reported cholera before the recent outbreak that started in October 2010, with over 720,000 cases and over 8700 deaths (Case fatality rate: 1.2%) through 8 december 2014. So far, this outbreak has seen 3 epidemic peaks, and it is expected that cholera will remain in Haiti for some time.

Methodology/findings: To trace the path of the early epidemic and to identify hot spots and potential transmission hubs during peaks, we examined the spatial distribution of cholera patients during the first two peaks in Artibonite, the second-most populous department of Haiti. We extracted the geographic origin of 84,000 patients treated in local health facilities between October 2010 and December 2011 and mapped these addresses to 63 rural communal sections and 9 urban cities. Spatial and cluster analysis showed that during the first peak, cholera spread along the Artibonite River and the main roads, and sub-communal attack rates ranged from 0.1% to 10.7%. During the second peak, remote mountain areas were most affected, although sometimes to very different degrees even in closely neighboring locations. Sub-communal attack rates during the second peak ranged from 0.2% to 13.7%. The relative risks at the sub-communal level during the second phase showed an inverse pattern compared to the first phase.

Conclusion/significance: These findings demonstrate the value of high-resolution mapping for pinpointing locations most affected by cholera, and in the future could help prioritize the places in need of interventions such as improvement of sanitation and vaccination. The findings also describe spatio-temporal transmission patterns of the epidemic in a cholera-naïve country such as Haiti. By identifying transmission hubs, it is possible to target prevention strategies that, over time, could reduce transmission of the disease and eventually eliminate cholera in Haiti.

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1. Introduction

Cholera is caused by *Vibrio cholerae*, and is transmitted through fecal-oral contact. Infection occurs after the ingestion of the bacteria and is usually asymptomatic. In a minority of cases, it causes acute diarrhea and vomiting, which can lead to potentially fatal severe dehydration, especially in the absence of appropriate medical care. Immunity occurs after infection and typically lasts 6–36 months (Ali et al., 2011; Weil et al., 2012).

In October 2010, cholera unexpectedly arrived in Haiti, affecting a population already devastated by the consequences of the January 2010 earthquake (Bilham, 2010). Since cholera had not been present in Haiti for at least a century (Jenson and Szabo, 2011) the outbreak struck an immunologically naïve population and, within a month, cases were reported throughout the country (MSPP, 2015). To date, the epidemic has seen 3 large peaks—November 2010, June 2011 and June 2012. The overall burden has been vast, with over 720,000 cases and over 8700 deaths (Case fatality rate: 1.2%) through 8 December 2014 (MSPP, 2015).

The first patients were reported in Mirebalais, a small town the Center department. The outbreak spread rapidly along the Artibonite River, presumably due to contamination of the water (Piarroux et al., 2011). Soon thereafter, health centers began reporting large numbers of patients in the communes (subdivisions of departments) along the lower Artibonite River (Petite Rivière, Vérettes, l'Estère and Saint Marc). Artibonite department has reported over 136,000 cases to date, the second highest number after the capital, Port-au-Prince.

Almost immediately after the first reported cases, Haiti's Ministry of Health (MOH) set up a dedicated cholera surveillance system to record cholera patients and deaths. Aggregated data were (and continue to be) reported to the MOH according to the department and the commune in which the patients were treated. These data, regularly updated, have been available online since the beginning of the epidemic. An overview of cases reported in this surveillance system during the first two years of the epidemic was published in February 2013 (Barzilay et al., 2013).

Given the size of the epidemic and relatively weak infrastructure, these data are impressive. Nonetheless, there is little information available at resolutions below the commune level (i.e., by communal section and village). In a few instances during outbreak phases, the MOH, various non-governmental organizations and local health workers would perform ad hoc analyses of the geographic origin of patients at these lower levels in order to better target interventions (prevention measures, awareness-raising activities, water treatment and rapid access to rehydration therapy). This data was used solely for operational purposes and has not been published, to the best of our knowledge. The overall distribution of cases at the level of communal sections and villages therefore remains unknown. However, several authors have pointed out the need for high resolution mapping, in order to show transmission heterogeneities and better target interventions (Mukandavire et al., 2013; Blackburn et al., 2014).

The population of Artibonite is 1.5 million inhabitants (DSDS, 2009). It is the second-most populated department after the Ouest Department which includes the capital, Port-au-Prince. Its topography is varied, with densely populated plains and major cities along the Artibonite River and the Caribbean coast, as well as sparsely populated mountainous areas with remote villages. The department produces many agricultural goods, and is home to some of the country's busiest markets, attracting people both from Port-au-Prince and also the northern departments.

The vast Artibonite estuary is prone to flooding during the rainy season (Tennenbaum et al., 2013). Considering its high population density and poor sanitation (Ecodev, 2013), there is a high risk for continued cholera transmission in the area. The area was also severely affected by hurricanes in 2004 (Franklin et al., 2006) and 2008 (Brown et al., 2010) and is likely to be hit again. All these factors are potential contributors to endemic settling of cholera in the area. This geographical and economic diversity, together with the large number of reported cholera patients, makes the Artibonite a priority region for more detailed spatial analysis of the cholera epidemic (Fig. 1).

We therefore undertook a study to describe the spatial dissemination of cholera in the Artibonite department at a sub-communal level. Our objectives were two-fold: first, to understand the dynamics cholera transmission in Artibonite and second, to demonstrate the feasibility and value of high-resolution spatial mapping for targeting prevention activities and planning outbreak responses.

2. Methodology

2.1. Spatial unit of analysis and map sources

Data were analyzed at the communal section level, the smallest administrative division for which population data were available from the last census (in 2003). Population data were also available for several towns in Artibonite but not for villages or hamlets. These data were adjusted using an annual growth rate of 1.64% (DSDS, 2009). Patients originating from outside Artibonite and seeking treatment in Artibonite were excluded.

Artibonite is divided into 15 communes, in turn divided into 63 communal sections. Nine major cities were considered independently, bringing the total number of political subdivisions analyzed to 72. These 9 cities had population census available in the national demographic data (reference), and therefore could be included as separate entities in the analysis. Other smaller cities with unavailable population data where included in their section communales. Lists of village names in each communal section were compiled from several sources (Open Street Maps, Direction Nationale de l'Eau Potable et de l'Assainissement DINEPA, Mission des Nations Unies pour la Stabilisation en Haiti MINUSTAH, MOH sources) as well as direct observation in the field.

Maps designed by MINUSTAH were modified for this study using ArcGIS software.

2.2. Study period

The time unit used for analysis was the epidemiological week, defined from Sunday at 12 a.m. to the following Sunday at 12 a.m.

The study period extended from October 2010 (epidemiological week 42), when the first cholera patients were reported, to the end of 2011 (epidemiological week 52). For these analyses, Phase 1 was considered to run from week 42-2010 to week 12-2011, and Phase 2 from week 13-2011 to week 52-2011. The transition point was set after the minimum number of weekly cases between the first two epidemic peaks during week 12 (Fig. 2).

2.3. Case definition

Following MOH definitions, a suspected cholera case was a patient (including children less than 5 years of age) reporting at least three liquid stools in the previous 24 h.

All patients seen and notified on the health facility registers (hospitalised or treated as out patients) were included in this study.

2.4. Data sources

During the study period, patients with suspected cholera were treated in dedicated health facilities throughout the department. Upon entry, the following information was recorded in admission registers: date of admission, date of first symptoms, age, gender,