Impact of Drainage Networks on Cholera Outbreaks in Lusaka, Zambia

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Objectives. We investigated the association between precipitation patterns and cholera outbreaks and the preventative roles of drainage networks against outbreaks in Lusaka, Zambia.

Methods. We collected data on 6542 registered cholera patients in the 2003–2004 outbreak season and on 6045 cholera patients in the 2005–2006 season. Correlations between monthly cholera incidences and amount of precipitation were examined. The distribution pattern of the disease was analyzed by a kriging spatial analysis method. We analyzed cholera case distribution and spatiotemporal cluster by using 2590 cholera cases traced with a global positioning system in the 2005–2006 season. The association between drainage networks and cholera cases was analyzed with regression analysis.

Results. Increased precipitation was associated with the occurrence of cholera outbreaks, and insufficient drainage networks were statistically associated with cholera incidences.

Conclusions. Insufficient coverage of drainage networks elevated the risk of cholera outbreaks. Integrated development is required to upgrade high-risk areas with sufficient infrastructure for a long-term cholera prevention strategy. (*Am J Public Health.* 2009;99:1982–1987. doi:10.2105/AJPH.2008.151076)

Cholera is still a global threat to human health in developing countries. According to the World Health Organization (WHO), the number of cholera cases significantly increased in 2006 after a period of relative decline; 52 countries officially reported cholera that year, with a total of 236 896 cases and 6311 deaths (case fatality rate=2.66%).[1] In recent years, most of the world's cholera cases have been recorded in sub-Saharan Africa, where endemicity is exacerbated by poor living conditions.[2,3]

Cholera dynamics in endemic regions display regular seasonal cycles and pronounced interannual variability, which are related to climate patterns such as temperature and precipitation.[4–6] Studies in coastal regions have indicated that cholera incidence is associated with sea surface temperature and precipitation, and zooplankton blooms have been posited as a possible mechanism for cholera transmission.[7–9] Although the seasonality of cholera outbreaks exhibits remarkable regularity, the pattern varies geographically depending on local socioeconomic determinants. Moreover, the association of cholera dynamics in inland regions with climate factors has not been fully investigated.

Because cholera is a water- and foodborne disease spread through fecal–oral transmission, contaminated water is a common vehicle of transmission.[10] Insufficient infrastructures for safe water, hygiene, and sanitation are recognized as major factors that contribute to cholera outbreaks.[11–13]

Zambia, an inland country in the middle of southern Africa, is bordered by Tanzania, Zimbabwe, Angola, Democratic Republic of the Congo, Namibia, Malawi, and Mozambique. Historically, the country has endured cholera outbreaks during its annual rainy season. The central government and cooperating partners have developed educational materials on safe water facilities, hygiene, and sanitation in an effort to prevent and control the disease's spread; however, Lusaka, Zambia's capital, continues to experience major cholera outbreaks.

In a previous spatial risk factor analysis of a cholera outbreak in 1 of the peri-urban areas of Lusaka, we reported that a higher incident rate of cholera was statistically associated with lower coverage of effective drainage systems and latrines.[14] Because the drainage systems were not strategically planned but were installed as supplements to road construction, they are segmented and poorly integrated. During the rainy seasons, these inadequate drainage networks cause substantial flooding, which can result in the spread of pathogens through runoff, increasing the risk of contamination.[15] To formulate an effective control and preventive strategy, the seasonality of cholera, its association with precipitation patterns, and the impact of insufficient social infrastructures need to be thoroughly investigated.

Using a spatial analysis method, we investigated the geographic pattern of cholera outbreaks, as well as the impact of precipitation patterns and drainage networks on the outbreaks in the 2003–2004 and 2005–2006 rainy seasons in Lusaka.

METHODS

According to a projected estimate based on the national census in 2000, Lusaka had a population of 1 676 322 in 2006. The city represents more than 10% of Zambia's population and has been growing rapidly through the influx of immigrants from rural into peri-urban areas, where access to safe water and to sanitation and hygiene facilities is limited.

The Lusaka District Health Management Team, which is a local authority of the Ministry of Health, is responsible for the provision of curative and preventative health services. The Lusaka District Health Management Team manages 25 health centers, most of which provide outpatient, inpatient, mother and child health, maternity, and laboratory services. During cholera outbreaks, the health centers in epidemic areas are assigned as cholera transit centers, where patients suspected of having cholera are provided with rehydration treatments and screened for referral to a cholera treatment center.

Case Definition

For each outbreak season, the cholera index case was confirmed by a laboratory test. Rectal swabs of all patients suspected of having cholera were submitted to the University Teaching Hospital and to 1 of the health centers' referral laboratories. After the index case was confirmed by a laboratory test, subsequent cholera cases were identified by clinical diagnosis in accordance with the surveillance guidelines of the Ministry of Health of Zambia. The guidelines defined cholera cases as individuals who had had watery stools more than 3 times in the 24 hours prior to visiting health care services. The symptomatically diagnosed cholera cases were registered for this study. Stool specimens of 1 every 10 cholera patients were collected for quality assurance of clinical diagnosis.

Patient Data

Patients suspected of having cholera were first screened at the cholera transit center and referred to the cholera treatment center if diagnosed with cholera. The cholera patient database was developed in collaboration with the Lusaka District Health Management Team to record the cholera patients' necessary information with Microsoft Access 2000 (Microsoft Corporation, Redmond, Washington). The annual outbreaks in the 2003–2004 and 2005–2006 seasons were selected for our study because more than 6000 cholera patients were recorded for each of these seasons, more than in any of the other 5 seasons preceding 2007. The database recorded a patient's name, age, gender, date of onset of symptoms, occupation, house address, and landmarks (any nearby building or facility that could be used to identify the house).

The 2005–2006 season was used for further investigation with spatial analysis. In 2005, we developed a geographic surveillance system with the Lusaka District Health Management Team to geographically analyze cholera case distribution in Lusaka. Environmental health officers and technologists from the public health administration traced the residential locations of the season's patients using a global positioning system (GPS). These personnel then delivered to the patients' houses contact tracing services, such as the disinfection of their premises and the provision of technical guidance on the causes and prevention of cholera to their family members.

Precipitation Data

Daily precipitation data (July 2003–June 2004 and July 2005–July 2006) were collected from the National Climatic Data Center of the US National Oceanic and Atmospheric Administration. Precipitation data were also measured at the meteorological station of the Lusaka International Airport, which is at the northeastern part of the study area (latitude 15° 19' 50.94" south, longitude 028° 27' 09.46" east, altitude 1152 meters). We checked both sets of precipitation data against those of the Zambia Meteorological Department and found consistency in precipitation patterns. The monthly amounts of precipitation were calculated from daily precipitation levels.

Geographical Analysis

We developed a digital base map from satellite imagery (SPOT 5 satellite, with 2.5-meter resolution) using ArcView version 8.2 (ESRI, Redlands, California); the map included streets, railroads, and public health facilities. The locations of cholera cases were recorded with GPS, and ArcView was used to construct a cholera patient map.

The distribution of cholera cases in the 2003–2004 and 2005–2006 outbreak seasons was examined with interpolating surface analysis. We calculated the average number of cases in the health center catchments for the 2 seasons. We applied an ordinary kriging geostatistical method to estimate values at unmeasured locations, using the average of the cases and locations of the health centers. Kriging is an interpolation method used to produce the optimal spatial-linear prediction. The method is used to construct a semivariogram, which is a graphic representation of the autocorrelation in a scatter point set as a function of distance. To produce the best linear unbiased estimate, prediction error is minimized in a least-squares sense.[16] The kriging method was carried out with ArcGIS version 9.2 and Geostatistical Analyst (ESRI, Redlands, California).

We analyzed clustering of the cases with retrospective space-time permutation scan statistics, using SaTScan version 7.0 (http://www.satscan.org) for the analyses. The statistic model uses millions of overlapping cylinders to define the scanning window, which is a possible disease cluster.[17] Monte Carlo hypothesis testing was used to evaluate the statistical significance ($P<.05$) of possible clusters.

To analyze the impact of drainage networks in the prevention of cholera outbreaks, we investigated the association of cholera incidence with drainage and stream networks. We mapped the drainage networks with ArcGIS, using physical observation to determine whether they were made from prefabricated components of reinforced concrete or were covered with flat stones and cement. We created a stream network using a digital elevation model data of Lusaka, using hydrologic modeling preinstalled in Spatial Analyst, ArcGIS. The 90-meter resolution digital elevation model data was obtained from SRTM (Shuttle Radar Topography Mission), which was initiated by the National Aeronautics and Space Administration to produce high-quality elevation data for all countries in the world. A 500-square-meter grid map was developed, and the lengths of drainage and surface streams within the grid area were measured for the analysis.

Statistical Analysis

Spearman rank correlation analysis was applied for identifying the association between monthly cholera incidences and amount of precipitation. Linear regression analysis for crude and multivariable models was used for analyzing the association of cholera cases with drainage and stream networks. The number of cholera cases within the grid area of 500 square meters was used as a dependent variable, and the lengths of drainage networks and streams within the same areas were used as independent variables for estimating regression parameters, with the crude model used for testing each variable separately and the multivariable model for adjusting the 2 variables. Because the population in the study area was not evenly distributed, we selected the grids that were within buffer circles around health centers to minimize population bias. The mean radius of the cluster circles identified with spatial analysis was used as the radius of the buffer circle. *P* values and 95% confidence intervals (CIs) were calculated with SPSS version 11.5 (SPSS Inc, Chicago, Illinois).

RESULTS

Seasonal cholera outbreaks were recorded from the beginning of the rainy season (September or October) to its end (May or June). In the 2003–2004 season, 6542 cholera cases and 187 deaths (case fatality rate=2.86%) were reported between November 28, 2003, and June 8, 2004. In the 2005–2006 season, 6045 cases and 148 deaths (case fatality rate=2.45%) were reported from August 26, 2005, to April 9, 2006. *Vibrio cholerae* O1 biotype El Tor Ogawa was confirmed at the University Teaching Hospital and Lusaka District Health Management Team laboratories for both seasons. The confirmed rates of *Vibrio cholerae*, determined at the laboratories from rectal swabs of registered patients, were 68% and 71% for the 2003–2004 and 2005–2006 seasons, respectively.

The leading age group of cholera patients was birth to 4 years old, which accounted for 20.1% and 18.2% of cases, respectively, in the 2003–2004 and 2005–2006 seasons (Table 1). Children younger than 9 years old accounted for 31.9% of cases in the 2003–2004 season and 31.1% in the 2005–2006 season. Among adults, patients aged between 25 and 29 years were the leading age group in both seasons.

Examination of the monthly distribution of cholera cases indicated that the peaks of both outbreaks occurred in January (Figure 1). Both seasons demonstrated almost the same precipitation patterns: rainy seasons started in November, reached their peak in February, and ended in April. The Spearman rank correlation analysis indicated significant correlation between the number of cholera cases and the amount of precipitation (Spearman $r=0.86$; $P<.01$).

TABLE 1—Demographic Information and Area Distribution of Cholera Cases in the 2003–2004 and 2005–2006 Rainy Seasons: Lusaka, Zambia

	Cholera Patients		
	2003–2004 Season, No. (%)	2005–2006 Season, No. (%)	Traced Cases,[a] 2005–2006 Season, No. (%)
Age group, y			
Birth–4	1317 (20.1)	1101 (18.2)	489 (18.9)
5–9	771 (11.8)	778 (12.9)	321 (12.4)
10–14	372 (5.7)	389 (6.4)	154 (5.9)
15–19	371 (5.7)	349 (5.8)	158 (6.1)
20–24	720 (11.0)	681 (11.3)	283 (10.9)
25–29	818 (12.5)	802 (13.3)	363 (14.0)
30–34	650 (9.9)	650 (10.8)	289 (11.2)
35–39	370 (5.7)	418 (6.9)	171 (6.6)
40–44	256 (3.9)	256 (4.2)	116 (4.5)
45–49	151 (2.3)	189 (3.1)	87 (3.4)
50–54	84 (1.3)	106 (1.8)	51 (2.0)
55–59	68 (1.0)	83 (1.4)	31 (1.2)
≥60	165 (2.5)	153 (2.5)	53 (2.0)
Unknown	429 (6.6)	90 (1.5)	24 (0.09)
Gender			
Female	3321 (50.8)	2922 (48.3)	1274 (49.2)
Male	3163 (48.3)	3123 (51.7)	1316 (50.8)
Unknown	58 (0.9)	0 (0)	0 (0)
Total	6542	6045	2590

[a]Traced with a global positioning system.

Kriging analysis clearly illustrated the distribution of cholera incidence (Figure 2a). The average number of registered cholera cases recorded at 19 health centers for the 2 outbreak seasons was used for the interpolation analysis. The cholera outbreak was concentrated in the western part of Lusaka, where 80.7% and 87.7% of total cases were reported for the 2003–2004 and 2005–2006 seasons, respectively. Incident rates in the western part of the city were 6.05 (per 1000 people) and 6.04 in the 2003–2004 and 2005–2006 seasons, respectively, whereas rates in the eastern part of the city were 0.80 and 0.93.

In the 2005–2006 season, 2590 cases (42.8% of total cases) were traced by GPS. A cholera patient map showed that 2263 patients (87.4%) resided in the western part of the city, which was clearly demarcated by the railway line (Figure 2b). Spatiotemporal analysis identified 4 significant clusters in the western part of the city, which included the Kanyama, Chawama, George, Chipata, and Mandevu areas (Figure 2b). The radius of each cluster circle ranged from 0.85 kilometers to 3.93 kilometers. Each cluster group included between 53 and 355 cases. The mean radius and the number of cases in the 4 space-time cluster circles were 1.86 kilometers and 171.5 cases, respectively. The outbreak started in the Kanyama health center area (cluster 1; August 18–November 30, 2005) and spread to the Chawama area (cluster 2; November 24–December 28, 2005) and then to the George area (cluster 3; December 8–December 21, 2005), with the 3 clusters overlapping in time. Subsequently, the fourth cluster was formed in the Chipata area (February 23–April 12, 2006) and was wider than the other 3 clusters.

For the association of cholera incidence with drainage and stream networks, linear regression analysis was applied. Surface streams were projected with a hydrology modeling method. Choropleth maps of the number of cholera cases and of the length of drainage networks are illustrated in Figure 2c and 2d. A total of 711 grids within a buffer circle of 1800 meters defined by spatiotemporal clusters were selected. The number of cholera cases in the selected grids ranged from 0 to 59 (mean=3.34; SD=8.26). The length of the drainage

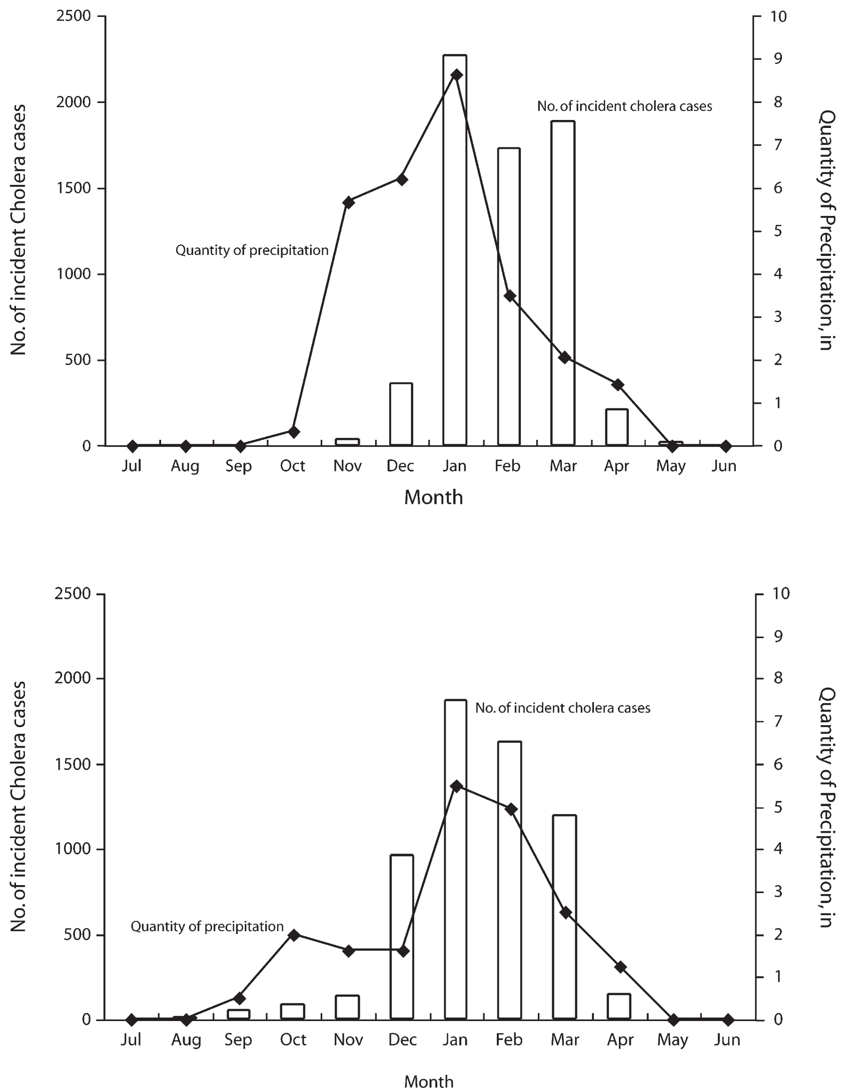

FIGURE 1—Monthly distribution of cholera cases and quantity of precipitation in Lusaka, Zambia, for the (a) 2003–2004 cholera season and (b) 2005–2006 cholera season.

network and surface streams in the grids ranged from 0 kilometers to 7.65 kilometers (mean=1.14; SD=1.48) and 0.22 kilometers to 5.72 kilometers (mean=1.58; SD=0.83), respectively. Linear regression analysis indicated that the length of the drainage network was statistically associated with the number of cholera incidences in both crude analysis (B=–1.18; 95% CI=–1.58, –0.78; SE=0.21; $P<.01$) and multivariable analysis (B=–1.18; 95% CI=–0.78, –1.59; SE=0.21; $P<.01$). However, the length of surface streams was not associated with cholera incidence in crude analysis (B=0.56; 95% CI=–0.18, –1.29; SE=0.37; $P=.14$) or multivariable analysis (B=0.58; 95% CI=–0.14, –1.29; SE=0.37; $P=.11$).

DISCUSSION

Cholera is a disease that exhibits sharp seasonal signals related to patterns of precipitation.[4,7,18] We found that in Lusaka, Zambia, cholera outbreaks occurred mostly during the rainy seasons and were strongly associated with the quantity of precipitation. Therefore, abundant rainfall is probably an important precursor in the occurrence of cholera outbreaks in this region.

The association of precipitation with cholera outbreaks was also affected by socioeconomic and geographic contexts. Studies in Bangladesh have shown a negative association between the number of cholera cases and the quantity of precipitation.[5,6,19] In Bangladesh and other coastal regions, precipitation reportedly dilutes the level of nutrients for zooplankton that serve as a reservoir for *V cholerae* and subsequently reduces the pathogens in aquatic environments.[7] On the other hand, other studies have indicated that precipitation increases cholera incidence by pushing moisture levels to optimum levels for pathogen-to-human transmission and flushing fecal contamination from dwellings into water sources in the dry regions of less-developed countries.[18,20] Thus, the role of precipitation in the transmission of the *V cholerae* should be investigated carefully with due consideration of the geographic, social, and environmental conditions in the epidemic areas, as well as the ecology of *V cholerae* and the pathogen's mode of transmission.

In a geographic distribution analysis of cholera incidence, more than 80% of total cholera cases in Lusaka were recorded in the western part of the city in each of the 2 outbreak seasons. We found that those geographic distributions strongly correlated with a town-planning policy for Lusaka instituted during the colonial period. Residential areas of the native population were segregated from the city's central areas, where the colonialists resided, to protect the latter from health-related contamination.[21,22] The native population's areas were separated by railway lines as a cordon sanitaire over which only 3 major roads crossed. This town-planning policy was aimed to minimize movement and contact between the people of the western and the eastern parts of the city, and consequently to control the transmission of disease. Our observations lead us to conclude that the city succeeded in controlling the transmission of cholera to the colonialist areas through its heritage of segregation. However, the segregated native residential areas still remained as peri-urban, unplanned settlements without sufficient access to safe water and proper hygiene and sanitation facilities.

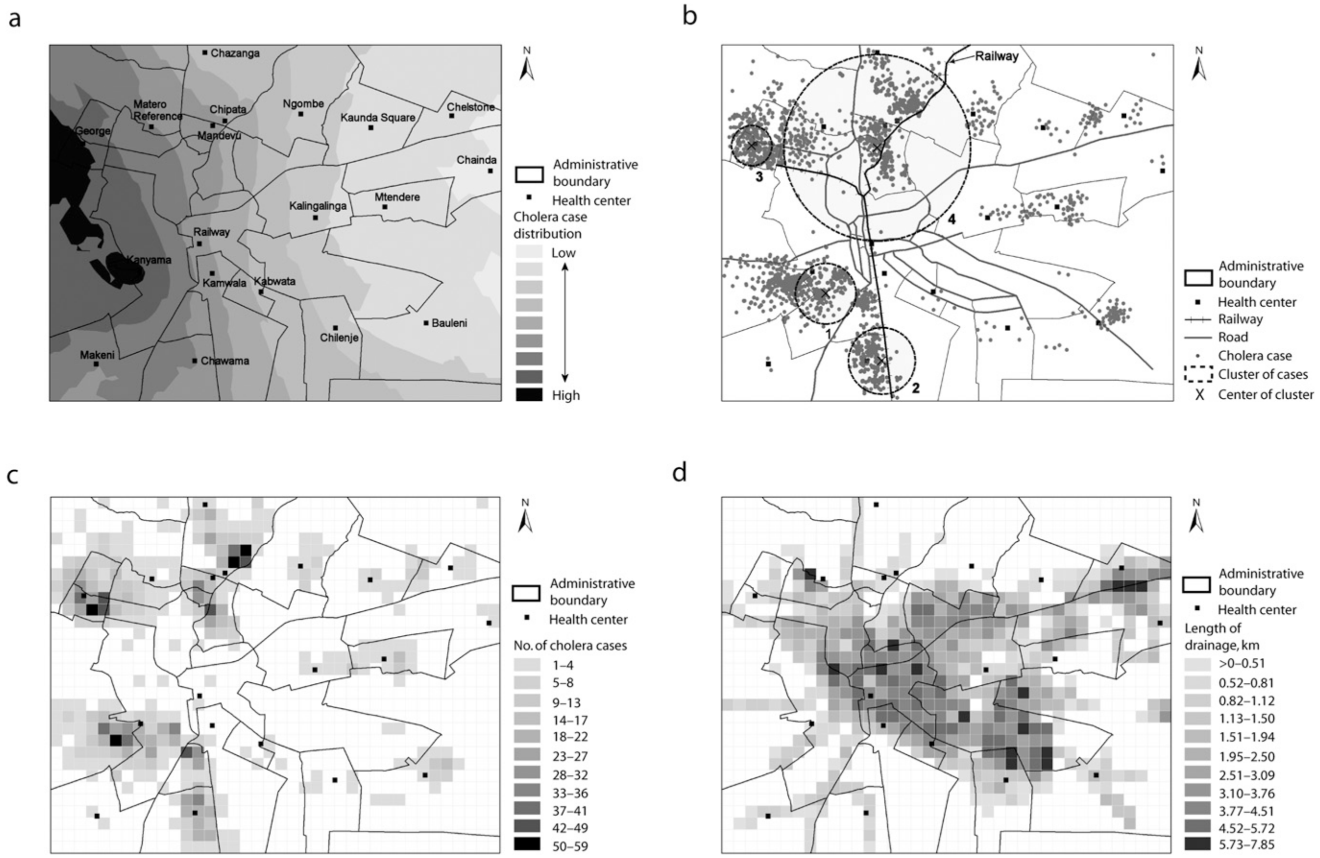

FIGURE 2—Study area of Lusaka, Zambia, showing (a) kriging analysis of cholera case distribution in 2003–2004 and 2005–2006 seasons, (b) cholera incidence map and clusters of space-time permutation analysis in 2005–2006 season, (c) choropleth map of number of cholera incidences in 2005–2006 season on 500-square-meter grids, and (d) choropleth map of length of drainage networks in 2005–2006 season on 500-square-meter grids.

In the association between precipitation and cholera incidence, insufficient coverage of drainage networks worsens environmental conditions by allowing the overflow of rainwater and increasing the risk of transmission of *V cholerae*. Our previous risk analysis of cholera outbreaks in Lusaka indicated that drinking water from open shallow wells was statistically associated with incidence of cholera.[14] Rainwater overflow commonly caused water in the wells to become contaminated through the flushing of human waste from surrounding houses into wells, and the increasing water levels caused channeling pathways to run through latrine pits. Our analysis indicated that less coverage of drainage networks was associated with higher incidence of cholera. This finding was consistent with other studies demonstrating the protective role of drainage networks for the prevention of diarrheal diseases, including cholera.[14,23] The current analysis also shows that natural surface streams did not play a protective role against cholera incidence, probably because the high-incidence areas are located on a plateau. Therefore, we emphasize that a well-planned infrastructure for drainage networks can minimize the overflow of rainwater and therefore reduce the risk of cholera transmission in many developing countries. We have no doubt that, in addition to drainage systems, the provision of facilities for safe water and excreta disposal also play major roles in the reduction of diarrheal diseases, including cholera. These combined interventions could have larger synergetic health impacts than any could alone.[24–27]

Global warming affects seasonality and the magnitude of diseases. Global mean temperature and precipitation patterns have changed in many regions, and changes will continue.[28,29] Global warming has already elevated the risk of cholera both geographically and temporally.[4,7] Changes in patterns of precipitation especially increase the risk of contamination in areas without sufficient infrastructures for drainage systems and watershed protection.[15,30] Therefore, it is important to assess the potential health impact of climate change and the capacity to respond to the change.[31] We assume that the methodology of risk analysis can be extended not only to cholera outbreaks in other areas but also to waterborne and vector diseases such as malaria, the reemergence of which are a serious concern because of global warming. Incorporating risk analysis into national health policies enables central and local authorities to take proactive rather than reactive approaches to establishing sufficient social infrastructures.

This study had certain limitations. Cholera cases were defined by symptomatology after an index case was confirmed by laboratory test. As the laboratory-confirmed rate of sample rectal swabs indicated, the number of registered cases in the study may be overestimated. Not all cholera cases were traceable with GPS, and only 42.8% of the cases were successfully marked on the cholera patient map. However, the proportion of the traced case distribution by area showed nearly the same proportion and order as the cases in the entire city. We therefore assume that the cholera case map minimized selection bias and represents the case distribution of the city. We succeeded in showing the impact of the drainage networks on cholera outbreaks in Lusaka, but the mechanism of how flooded water contributes to the incidences of cholera was not thoroughly investigated. Further analysis of the transmission of the pathogen in flood circumstances is required. A mathematical model should be developed with geographic information system technology to assess the impact of precipitation on incidences of cholera.

Our study contributes to elucidating the role of precipitation in the transmission and distribution patterns of cholera cases in Lusaka. The insufficient coverage of the drainage networks in the peri-urban areas was significantly associated with high incidences of cholera. Therefore, in addition to the need for rapid response to cholera outbreaks for control and prevention, integrated development to upgrade risk areas with sufficient infrastructure for drainage networks, safe water, hygiene, and sanitation should be strengthened for the long term, especially in inland urban cities in developing countries. ■

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Contributors

S. Sasaki designed and completed the analysis of the study and led the writing. H. Suzuki supervised all aspects of the study. Y. Fujino and M. Cheelo assisted with field research. Y. Kimura assisted with spatial analysis. All authors helped interpret findings and reviewed drafts of the article.

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Human Participant Protection

No protocol approval was needed for this study.

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