Short Report: Does Water Hyacinth on East African Lakes Promote Cholera Outbreaks?

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Abstract. Cholera outbreaks continue to occur regularly in Africa. Cholera has been associated with proximity to lakes in East Africa, and *Vibrio cholerae* has been found experimentally to concentrate on the floating aquatic plant, water hyacinth, which is periodically widespread in East African lakes since the late 1980s. From 1994 to 2008, Nyanza Province, which is the Kenyan province bordering Lake Victoria, accounted for a larger proportion of cholera cases than expected by its population size (38.7% of cholera cases versus 15.3% of national population). Yearly water-hyacinth coverage on the Kenyan section of Lake Victoria was positively associated with the number of cholera cases reported in Nyanza Province ($r = 0.83$; $P = 0.0010$). Water hyacinth on freshwater lakes might play a role in initiating cholera outbreaks and causing sporadic disease in East Africa.

INTRODUCTION

Cholera has been described as a paradigm of an infectious disease whose incidence and epidemiology is intricately linked with environmental factors, including water temperature and salinity, rainfall, algal blooms, El Niño occurrences, and wind direction.^{1–5} In recent years, Africa has accounted for an increasing proportion of the world's cholera burden.⁶ Conditions favoring cholera transmission—limited access to clean water and food and poor sanitation—are common in Africa today.⁶ There might also, however, be unique environmental factors promoting cholera outbreaks in Africa. Exposure to lakes has been shown to be epidemiologically linked with cholera disease in several East African countries.^{7–9} Many of the Great Lakes in East Africa have become colonized with an exotic plant, the water hyacinth (*Eichhornia crassipes*); it was first documented in Lake Victoria in 1988.^{10,11} We explore the temporal association between water-hyacinth coverage on Lake Victoria and cholera incidence in the Kenyan province bordering the lake.

METHODS

We obtained annual cholera case counts in Kenya reported to the World Health Organization (WHO) from 1994 to 2008.¹² Cholera cases reported in Nyanza Province, which borders Lake Victoria (population 4,392,196 from 1999 Census), were obtained from Nyanza Province Ministry of Health.¹³ Most cholera was not culture-confirmed but based on the WHO definition of a suspected cholera case in a confirmed cholera outbreak—watery diarrhea (three or more bowel movements in 24 hours) of sudden onset in a person ≥ 5 years.¹⁴ Annual rainfall amounts and mean air temperatures were calculated from measurements at Kisumu airport.¹⁵

Estimation of water-hyacinth coverage on Winam Gulf, which borders much of the Kenyan portion of Lake Victoria, was done by remote sensing of satellite imagery from 1994 to 2001 and after 2001, by ground truthing using global positioning system (GPS)-generated ground control points that were plotted using ARCVIEW GIS software (ESRI version 3.2,

Redlands, CA) on a digital map to yield polygons from which spatial coverage was computed, as described elsewhere (Figure 1).^{10,11} In most years, hyacinth coverage was measured two times annually. For graphical representation and statistical analysis, average annual hyacinth coverage and number of cholera cases were compared. In years with two measurements in the same half-year (i.e., 2007 and 2008), the average area for that half-year was used. In half-years without hyacinth measurements (i.e., first half of 2005 and first half 2008), extrapolated values were used based on the immediate measurements before and after. Statistical associations between annual variables (cholera cases, hyacinth coverage, rainfall, and temperature) were evaluated by Spearman rank correlation, proportions by χ^2 test, and medians by Wilcoxon rank sum test.

RESULTS

From 1994 to 2008, Nyanza Province reported 24,308 cholera cases, which represented 38.7% of reported cases in Kenya, more than double the percentage of the Kenyan population living in Nyanza (15.3%; $P < 0.001$).¹³ The percentage of national cholera cases in Nyanza was even higher during the outbreaks in 1997–1998 (43–49%) and 2008 (72%). Reported cholera cases in Nyanza peaked between 1997 and 1999, fell annually thereafter, dropped to zero in 2002–2006, and rose again in late 2007 through 2008 (Figure 2).

The peak cholera years of 1997–1999 also had the greatest hyacinth coverage on Winam Gulf, peaking in April 1999 (Figures 1 and 2). The hyacinth coverage had started to rise in the second half of 1996 (2,750 hectares) and first half of 1997 (5,250 hectares) before the cholera outbreak started in July 1997; the number of cholera cases peaked in 1998, whereas the hyacinth coverage peaked in 1999.⁹ No hyacinth was observed on the lake from early 2002 through late 2005, a period also without cholera. Hyacinth coverage rose again beginning in 2006, reaching a second peak in mid-2007. Throughout the time period, median hyacinth coverage in the first and second half of the year were not different ($P = 0.90$).

From 1994 to 2008, the number of cholera cases in Nyanza was significantly correlated with water-hyacinth coverage on Winam Gulf ($r = 0.83$; $P = 0.0010$). The correlation remained significant when removing the large cholera outbreak of 1997–1998 from the analysis ($r = 0.78$; $P = 0.0079$). Neither annual cumulative rainfall, ranging from 274 mm in 1999 to 1,789 mm in 2006, nor annual mean daily rainfall was associated with the

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FIGURE 1. Map of Winam Gulf of Lake Victoria in Kenya and satellite image of water-hyacinth coverage in December 2006. (Satellite photo from National Aeronautics and Space Administration (NASA) images; courtesy of moderate resolution imaging spectroradiometer (MODIS) Rapid Response Team, Goddard Space Flight Center.) This figure appears in color at www.ajtmh.org.

number of cholera cases in Nyanza ($P = 0.37$ and $P = 0.35$, respectively) (Figure 2). Mean annual air temperatures varied little annually (range = 22.31–23.76°C) and were not associated with the number of cholera cases ($P = 0.45$).

DISCUSSION

We showed a temporal association between cholera cases in Nyanza Province and the coverage of water hyacinth on Winam Gulf. Nyanza represented a disproportionate burden of Kenya's cholera cases, and both the large cholera outbreak in 1997–1998 and the smaller outbreak in 2008 occurred in Nyanza.^{9,12,16} *Vibrio cholerae* has been grown from water hyacinth in freshwater sources in India and Bangladesh.^{3,17,18} Isolation of *V. cholerae* was more frequent on hyacinth than in the surrounding water.¹⁸ Moreover, experimental introduction of hyacinth into water led to a 300-fold increase in

concentration of *V. cholerae* on the hyacinth itself compared with the surrounding water.¹⁸ Bathing and drinking lake water have been shown to be risk factors for disease in Lake Victoria and Lake Tanganyika, both East African lakes in which hyacinth is prevalent.^{7–11} A study in western Democratic Republic of Congo found that cholera outbreaks were more likely to occur and persist near lakes and that individual cholera cases were more likely among people living closer to the lakes.⁸ The experimental data along with the epidemiologic linkage of cholera to lakes suggest that hyacinth might act as a nidus for amplification and/or maintenance of a reservoir for *V. cholerae* that can lead to repeated infections among people drinking or swallowing lake water.

The temporal correlation between hyacinth and cholera is not exact, as evidenced by disjunction of peak cholera cases in 1998 and hyacinth coverage in 1999. After people bordering the lake become infected with cholera, the outbreak likely spreads

FIGURE 2. Relationship between annual number of cholera cases reported in Nyanza Province, water-hyacinth coverage area in Winam Gulf, Lake Victoria, and rainfall in Kisumu, Kenya, from 1994 to 2008.

through the established transmission routes of contaminated water and food, and it can disseminate rapidly around a country with a developed transportation system, like Kenya.^{6,19} Therefore, the characteristics of cholera outbreaks likely are dictated by other factors besides hyacinth, such as water and sanitation conditions for the magnitude and implementation of interventions and community-level immunity for the duration. Moreover, hyacinth is not the only possible potentiating factor for cholera outbreaks as supported by the occurrence of cholera in Kenya before the emergence of hyacinth in the late 1980s. We did not have Nyanza-specific cholera data before 1994 to evaluate the pre-hyacinth period.¹² Hyacinth's role, therefore, might be in the initiation of outbreaks and maintenance of sporadic disease in districts bordering lakes.

Our study has several limitations. First, the temporal linkage between hyacinth coverage and cholera burden does not prove causation. To establish causation, more environmental and epidemiologic studies are needed. Further environmental work might include measuring *V. cholerae* density and copepods that harbor the vibrios in lake water with and without hyacinth, including in the same area over time. Showing a positive measure of association, including a dose-response relationship, between direct exposure to hyacinth-laden lake water and cholera infection in people is also needed. Second, water-hyacinth blooms possibly coincide with other factors that might support *V. cholerae* growth.^{1,3} Of note, Kenya experienced El Niño disturbances in late 1997 and 2006 that caused flooding in the Lake Victoria Basin, which might have washed either hyacinth from river margins into the lake or the nutrients needed to support its growth.^{10,11,20} However, there was not temporal synchrony between El Niño flooding and cholera outbreaks, because the 1997 outbreak had started before the flooding and the 2008 outbreak began almost 1 year after El Niño rains.^{9,16} Third, water-hyacinth mats often incorporate other vegetation, particularly hippo grass (*Vossia cuspidata*), whose role in supporting cholera is unknown; other aquatic plants, like common duckweed, have been shown to enhance *V. cholerae* survival.^{11,21} Fourth, cholera reporting is incomplete in Kenya, and the degree of incompleteness likely varies by year. For instance, during the post-election violence in early 2008, cholera case reporting was hindered by disruptions in the public health infrastructure. Lastly, hyacinth measurements were done only every 6 months and in some cases, 1 year apart, and interim extrapolations of hyacinth coverage might have been inaccurate. Hyacinth populations can crash rapidly because of natural succession mechanisms or could have been reduced substantially by human interventions, such as use of herbicides and weevils.¹¹ Moreover, being able to quantify cholera cases and hyacinth coverage in shorter time intervals, such as 3-month blocks, would have allowed for closer analysis of the temporal correlation. However, neither cholera nor hyacinth shows clear seasonality in western Kenya, so that our annual-level analysis is unlikely to obscure seasonal associations between cholera and hyacinth.^{9,16,19}

Although the association that we show between water hyacinth and cholera needs further study, it could have important public health implications. If confirmed, Ministries of Health might consider focal, enhanced cholera surveillance, education, and health facility preparedness for cholera case management (e.g., oral and intravenous rehydration supplies) in areas bordering lakes during times of significant water-hyacinth coverage. Moreover, efforts to remove water hyacinth

from lakes might be enhanced where large populations reside in close proximity to the lake.^{10,11}

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REFERENCES

- Colwell RR, 2004. Infectious disease and environment: cholera as a paradigm for waterborne disease. *Int Microbiol* 7: 285–289.
- Constantin de Magny G, Guegan JF, Petit M, Cazelles B, 2007. Regional-scale climate-variability synchrony of cholera epidemics in West Africa. *BMC Infect Dis* 7: 20. doi:10.1186/1471-2334-7-20
- Huq A, Sack RB, Nizam A, Longini IM, Nair GB, Ali A, Morris JG Jr, Khan MN, Siddique AK, Yunus M, Albert MJ, Sack DA, Colwell RR, 2005. Critical factors influencing the occurrence of *Vibrio cholerae* in the environment of Bangladesh. *Appl Environ Microbiol* 71: 4645–4654.
- Lobitz B, Beck L, Huq A, Wood B, Fuchs G, Faruque AS, Colwell R, 2000. Climate and infectious disease: use of remote sensing for detection of *Vibrio cholerae* by indirect measurement. *Proc Natl Acad Sci USA* 97: 1438–1443.
- Paz S, Broza M, 2007. Wind direction and its linkage with *Vibrio cholerae* dissemination. *Environ Health Perspect* 115: 195–200.
- Mintz ED, Guerrant RL, 2009. A lion in our village—the unconscionable tragedy of cholera in Africa. *N Engl J Med* 360: 1060–1063.
- Birmingham ME, Lee LA, Ndayimirije N, Nkurikiye S, Hershs BS, Wells JG, Deming MS, 1997. Epidemic cholera in Burundi: patterns of transmission in the Great Rift Valley Lake region. *Lancet* 349: 981–985.
- Bompangue D, Giraudoux P, Handschumacher P, Piarroux M, Sudre B, Ekwanzala M, Kebela I, Piarroux R, 2008. Lakes as source of cholera outbreaks, Democratic Republic of Congo. *Emerg Infect Dis* 14: 798–800.
- Shapiro RL, Otieno MR, Adcock PM, Phillips-Howard PA, Hawley WA, Kumar L, Waiyaki P, Nahlen BL, Slutsker L, 1999. Transmission of epidemic *Vibrio cholerae* O1 in rural western Kenya associated with drinking water from Lake Victoria: an environmental reservoir for cholera? *Am J Trop Med Hyg* 60: 271–276.
- Albright TP, Moorhouse TG, McNabb TJ, 2004. The rise and fall of water hyacinth in Lake Victoria and the Kagera River Basin, 1989–2001. *J Aquat Plant Manage* 42: 73–84.
- Lake Victoria Basin Commission, 2008. *Studies on Rapid Assessment of the Ecological Succession and the Dynamic Status of Water Hyacinth Eichhornia Crassipes (Mart.) Solms-Laubach in the Nyanza Gulf of Lake Victoria, Kenya: Report to Lake Victoria Basin Commission.*
- World Health Organization, 2008. *Cholera. Number of Cases: WHO.* Available at: <http://apps.who.int/globalatlas/>. Accessed November 23, 2009.
- Kenya Central Bureau of Statistics, 2001. *1999 Population and Housing Census. Volume 1: Population Distribution by Administrative Areas and Urban Centers.* Nairobi, Kenya: Kenya Central Bureau of Statistics.
- World Health Organization, 2004. *Cholera Outbreak: Assessing the Outbreak Response and Improving Preparedness.* Geneva, Switzerland: World Health Organization.

15. National Climatic Data Center, 2009. *Federal Climate Complex, Global Surface Summary of Day Data, Version 7: National Oceanic and Atmospheric Administration*. Available at: <http://www.ncdc.noaa.gov/cgi-bin/res40.pl?page=gsod.html>. Accessed February 20, 2010.
16. Shikanga OT, Mutonga D, Abade M, Amwayi S, Ope M, Limo H, Mintz ED, Quick RE, Breiman RF, Feikin DR, 2009. High mortality in a cholera outbreak in western Kenya after post-election violence in 2008. *Am J Trop Med Hyg* 81: 1085–1090.
17. Bhanumathi R, Sabeena F, Isac SR, Shukla BN, Singh DV, 2003. Molecular characterization of *Vibrio cholerae* O139 Bengal isolated from water and the aquatic plant *Eichhornia crassipes* in the River Ganga, Varanasi, India. *Appl Environ Microbiol* 69: 2389–2394.
18. Spira WM, Huq A, Ahmed QS, Saeed YA, 1981. Uptake of *Vibrio cholerae* biotype eltor from contaminated water by water hyacinth (*Eichhornia crassipes*). *Appl Environ Microbiol* 42: 550–553.
19. Mugoya I, Kariuki S, Galgalo T, Njuguna C, Omollo J, Njoroge J, Kalani R, Nzioka C, Tetteh C, Bedno S, Breiman RF, Feikin DR, 2008. Rapid spread of *Vibrio cholerae* O1 throughout Kenya, 2005. *Am J Trop Med Hyg* 78: 527–533.
20. Olago D, Marshall M, Wandiga SO, Opondo M, Yanda PZ, Kanalawe R, Githeko AK, Downs T, Opere A, Kavumvuli R, Kirumira E, Ogallo L, Mugambi P, Apindi E, Githui F, Kathuri J, Olaka L, Sigalla R, Nanyunja R, Baguma T, Achola P, 2007. Climatic, socio-economic, and health factors affecting human vulnerability to cholera in the Lake Victoria basin, East Africa. *Ambio* 36: 350–358.
21. Islam MS, Drasar BS, Bradley DJ, 1990. Survival of toxigenic *Vibrio cholerae* O1 with a common duckweed, *Lemna minor*, in artificial aquatic ecosystems. *Trans R Soc Trop Med Hyg* 84: 422–424.