A spatial analytic approach to examine Shigella transmission

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Abstract (149 words)
Diarrheal diseases are one of the leading causes of death worldwide among children under five. Among the enteric pathogens that cause diarrhea, shigella is particularly problematic due the severity of disease associated with shigellosis and the low infectious dose that facilitates transmission. While person-to-person transmission through fecally contaminated hands is considered the primary route of infection, mechanical vectors (predominantly houseflies) are also an important cause of transmission. This research draws upon a prospective longitudinal case-control surveillance study of children under five in Santa Clara, Peru to examine factors associated with the transmission of shigella. Focusing on the hypothesis of fly-related shigella transmission, a spatial model of fly density is developed using community-wide fly capture data over a three-year period. Spatial predictions are then made to estimate fly densities throughout the community and a space-time model of shigella is developed to test the importance of fly density on shigella transmission.

EXTENDED ABSTRACT

Introduction
Diarrheal diseases are one of the leading causes of death worldwide among children under five (World Health Organization (WHO) 2005). While improved case management has improved outcomes from acute dehydrating diarrhea, the use of oral rehydration therapy has increased the importance of dysentery and persistent diarrhea as causes of severe disease. Shigella, which is the principal cause of the clinical dysentery syndrome, is the enteric infection that is most consistently associated with prolonged acute episodes and the development of persistent diarrhea. In addition, Shigella is a major cause of diarrhea in young children in the developing world, causing between 2.3% and 5.3% of all diarrheal disease in infants and 5.5%-18.7% of all diarrheal episodes in children between 1-5 years of age detected by active surveillance.

The major factor that distinguishes routes of transmission for Shigella from other enteric infections is the low infectious dose. Clearly, like all enteric infections, transmission is fecal-oral. However, because the infectious dose is so low and because the organism is relatively unstable in the environment, routes of transmission are suspected to differ from other enteric infections. Populations in Israel and Chile with potable water supplies and low rates of overall diarrheal illness continue to have well-documented high incidence rates of Shigella. Currently, the major routes of transmission are felt to be person to person spread by fecally contaminated hands and by mechanical vectors, predominantly houseflies.

The influence of house flies in increasing the probability of transmission of diarrheal disease has never been consistently demonstrated. It has been observed that peak fly densities coincide with peak seasonal diarrheal disease reporting. In addition, research has observed high fly densities to precede outbreaks of dysentery. Since shigella (among other enteropathogens) can be cultured from pools of captured flies it is a reasonable argument that flies act as a key mechanical vector for shigella disease transmission. While a causal link has never been shown, indirect evidence has demonstrated a drop in Shigella infections following implementation of fly control interventions. A study conducted in 1946 by Watt and Lindsay used DDT in two groups of towns in Texas to test the implementation of a fly control program on diarrheal disease. The found that Shigella isolation rates decreased significantly in the intervention group (Watt and Lindsay 1948). A similar study by Lindsay, Stewart and Watt conducted in Georgia resulted in the same conclusion (Lindsay, Stewart et al. 1953). A recent study conducted in Israel implemented a control program that decreased fly counts by 64% and an observed decrease in seropositive shigella by 76% combined with a decrease in clinic visits by 85% (Cohen, Green et al. 1991). A study in Pakistan using a deltamethrin derivative resulted in a decrease in the incidence of diarrhea in children under 5 by 23% (Khalil, Lindblom et al. 1994). Despite strong evidence for the importance of fly control, WHO still considers it an ineffective strategy to prevent diarrheal disease.

The use of geographic information systems (GIS) combined with spatial analytic techniques to track infectious disease is a growing field. Individual cases or the isolation of a pathogen of interest can be easily and quickly linked to other geographic data systems that are existing and available. Such databases may describe the source of water, routes of transportation, temporal / seasonal fluctuations, topographical data, demographic data, or meteorological data. The power of GIS to augment statistical procedures allows for a more complete evaluation of the prevalence and incidence of disease or the isolation of a pathogen of interest through a more thorough analysis of the distribution of cases in a population. The present application demonstrates the importance of geo-coding data to study aspects of infectious disease transmission and to identify spatial factors influencing disease outcomes.

Study site, deaign and data collected

The research presented in this paper was conducted in Santa Clara, a periurban community (population 2574, December 2000 Census) located approximately 30 minutes (10 km) from the urban center of Iquitos, the largest city in the Peruvian Amazon. The population is dependent upon farming of individual group plots, fishing, or forestry. Mean monthly income is approximately $24 USD. The majority of the population live in semi-permanent housing: 90% have dirt floors and 74% have roofs of palm and/or plastic. The mean household size is 48 m^2 with a mean of 6.4 persons per household. There is no public sewage and 78% of the population uses a well or open space for excrementation (“canals” are dugout throughout the community that serve to drain water from the house and transport feces and urine, but these are open air canals rather than covered).

The target study population is children aged 5 years and younger. Among the 2574 persons living in the community, 474 were under age 5 in December 2000. Community participation in diarrheal surveillance is high – our previous enrollment had a response rate of 94% for a one year period and only one child withdrew. The study design implemented here involved 360 age-stratified children (<12 months, 13-23 months, 24-35 months, 36-47 months, 48-59 months) randomly selected for longitudinal surveillance (only one child per household was allowed to participate). Community health workers visited the household 3 times per week to check for diarrhea and dysentery cases for the child. Monthly anthropometry data was collected and quarterly stool surveillance was collected to detect asymptomatic infection. If a child presented with an episode of diarrhea, stool was collected for occult blood testing and culture. If shigella was isolated a random age-matched child was selected into the study and active child/household surveillance was conducted for 28 days to detect further cases of shigella. Risk factor questionnaires were administered to each case and control household. If no shigella was detected the child was treated for appropriately and disease surveillance continued.

Additional data collected include the following: **Fly samples** were collected from four fixed sites every fifteen days over the entire study period *plus* fly capture data from every case and matching control household at various time points; **Surface water** was tested also tested from four fixed sites every fifteen days over the entire study period; **Hand swabs** and fingers / fingernails in particular were tested for the presence of shigella; **Geographic data** were collected for the entire community – all households were mapped into a GIS, “sewage canals”, locations of latrines, roads, public buildings, topography (low lying areas), river location (high / low seasonal changes), and other important community infrastructure; and **Climate** data consisting of daily rainfall and temperature data from the Iquitos airport, which is less than 10 km from Santa Clara.

Analysis plan / Objectives of the paper

The basic idea of analysis involves two complimentary approaches: (1) a thorough descriptive analysis that includes spatial mapping of cases overlaid with spatially predicted fly densities for every 2-3 months of surveillance, rainfall data, and other risk factors associated with shigella; and (2) the development of a spatial model of shigella incidence. The model would resemble the following:

$$y_{i,t} = \alpha_0 + X_{t-2}^{Rain}\beta_{t-2} + X_{t-1}^{Rain}\beta_{t-1} + X_t^{Rain}\beta_t + X_{km2canal}\beta_{canal} + e$$

Where the outcome, y, is a function of rainfall in previous time points, distance to canals, and a spatially predicted fly density (parameter not shown). A kriging model (spatial prediction model) would be used to predict fly densities over time and we would utilize that model to assign fly density values to unobserved time points and locations in our model.

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