Epidemiological investigation of an outbreak of acute diarrhoeal disease using geographic information systems

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Summary An outbreak of acute diarrhoeal disease in a village in southern India was investigated through personal interviews of all households. Maps were drawn using geographic information system (GIS) tools of the water supply system, sewage channels and areas with observed faecal contamination of soil within and around the village. Geographic coordinates for each house in the village were extracted from a central database from the healthcare service provider for the village. Geographical clustering of cases was looked for using the SaTScan software, and diarrhoeal disease attack rates were calculated. Diarrhoeal disease occurred uniformly throughout the village without clustering in any area. All ages and both sexes were affected, but extremes of ages were at higher risk. Water samples collected for microbiological examination after instituting control measures showed high coliform counts. Chlorine levels in the water tested were found to be inadequate to decontaminate common pathogens. Local cultural practices such as indiscriminate defecation in public places, washing clothes and cleaning utensils from water taps where the community collected its drinking water, and poor engineering design and maintenance of the water supply system were the risk factors that could have contributed to this outbreak.

1. Introduction

Contaminated drinking water continues to be the source for most diarrhoeal outbreaks recorded in India (Bhattacharya et al., 2000; Chakraborty et al., 1981; Ramakrishna et al., 1996; Sur et al., 2002; Taneja et al., 2003).
In recent years, global positioning system (GPS) and geographic information system (GIS) tools for spatial mapping have been used for investigation of outbreaks in industrialised countries, in addition to conventional epidemiological methods. In an outbreak investigation, the use of GIS not only provides useful maps for communication of findings and dissemination of information and for health education, but also an insight into epidemiological linkages with potential causes or risk factors.

An outbreak of diarrhoeal disease in a village in southern India was investigated using spatial mapping. The implications of the results for water safety and management in rural areas are discussed.

2. Methods

2.1. Study area

The Kaniyambadi Harijan Colony (12.813964 N, 79.132305 E), in Kaniyambadi block, is a cluster of houses located to the west of a state highway from Vellore in the north to Arni in the south. The main village of Kaniyambadi is to the east of the highway, where there was no outbreak or reported cases. Community Health and Development (CHAD) hospital and its healthcare team provide primary and secondary health care in this and the surrounding villages.

2.2. Study population

In 2004, the total population of the colony was 1118 permanent residents, comprising 578 females and 540 males. Adult literacy in the colony was approximately 70% and the majority of residents were beedi makers or manual labourers (Community Health Department census 2003, unpublished data). Of the total population, 13% belonged to the high, 48% to the middle and 39% to the low socioeconomic status (SES). This SES scoring system used the Modified CHAD SES Scale, with the parameters caste, type of house, land owned, and education and occupation of the head of the household (Raghava, 2004, unpublished MD dissertation).

2.3. Data collection

On 1 November 2004, two patients from the colony, a 37-year-old male and a 60-year-old female, presented to the CHAD hospital emergency room, 7 km from Kaniyambadi village, with acute gastroenteritis and >10% dehydration. They reported that many others in their colony were similarly ill. Stool cultures from both patients grew *Vibrio cholerae* O1.

A rapid survey of the colony, conducted by a doctor from CHAD hospital, identified approximately 30 individuals with diarrhoeal episodes in the previous 2 weeks. For the investigation that followed, a case was defined as any person in the colony passing three or more watery stools, abdominal pain, fever, vomiting and nature of treatment undertaken, if any. Residents were also questioned about food eaten outside the home in the week preceding the illness, a history of travel outside of the colony and similar illness in other family members in the preceding week. The questionnaire also contained information on the source of drinking water for each household. The investigation was carried out with the approval of the Community Health Department of the Christian Medical College, Vellore, and the local health authorities. Special ethical clearance for this outbreak investigation was not sought, since the investigators were part of the team that provides primary and secondary care to the residents of the area.

Each house in the colony was linked with the CHAD database using a unique identification number and the geographic coordinates (latitude, longitude) extracted from this database. All the taps in the colony were mapped using a GPS receiver and assigned unique identification numbers. The information regarding drinking water for each household was linked to the tap to calculate tap-specific attack rates. The water supply network of the entire colony was mapped by walking over the pipeline with a GPS receiver and information was collected regarding breaks in the pipeline in the past as well as subsequent repairs. Sewage disposal of the colony was surveyed and places with evidence of faecal contamination were also mapped by direct observation and walking around the perimeter of the contaminated areas with a GPS receiver. Concentric circles (buffers) were drawn around the tanks at increasing distances, and attack rates and relative risks (RR) (with 95% CI) were calculated.

The amount of bleaching powder added to disinfect the water was ascertained by questioning the ‘pump-driver’ of the colony who was responsible for pumping water to the overhead tanks, chlorinating water in overhead tanks and opening the valves of the distribution system. Information was obtained regarding the timing of pumping, the amount of bleaching powder added (both normally and during the outbreak) and the standing time for water to mix with bleaching powder.

Towards the end of the period of intensive surveillance for new cases, water samples were collected for microbiological assessment. These samples were collected from each of the two overhead tanks as well as from five randomly chosen taps at different locations in the colony. Water samples were tested for presumptive coliform counts and for the presence of *V. cholerae* using previously described methods (Ramakrishna et al., 1996).

Over the duration of the outbreak, the health authorities transferred patients requiring rehydration to local hospitals and provided doxycycline as prophylaxis to the household contacts of cases. The community was advised to boil its drinking water.

2.4. Statistical analysis

Data were entered in Microsoft Excel 2002 (Microsoft Corp. 1985–2001) and statistical analysis was done using Epi Info 6.04 software (CDC, Atlanta, GA, USA). Attack rates and RRs (with 95% CI) were calculated. The two-tailed $\chi^2$ test was
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2.5. Spatial mapping and analysis

Garmin GPS V (Garmin International Inc., Olathe, KS, USA) was used for collecting waypoints and trackpoints (latitude, longitude). These were then downloaded using GPS Utility 4.10.4 (GPS Utility Ltd., Southampton, UK) and mapped using ArcView GIS 3.3 software (Environmental Systems Research Institute Inc., Redlands, CA, USA). Water and sewage maps were layered with maps of the streets, houses and water taps.

To explore the spatial distribution of diarrhoeal cases and to identify significant spatial clusters, if any, SaTScan 6.1.3 software (Information Management Services Inc., Silver Spring, MD, USA) was used. The unit of analysis was considered to be a household. For this analysis, any household with one or more cases was considered to be a case household, and a household where there were no cases was considered to be a non-case household. This software moves a circular window systematically throughout the geographic space to detect significant spatial clusters of cases. The radius of the window varies from zero to a user-defined upper limit. For this analysis, the upper limit of the circular window was specified as the geographic size that includes 50% of the study population, allowing both small and large clusters to be detected whilst ignoring clusters that contain more than 50% of the population (Kulldorff and Nagarwalla, 1995). The distribution and P-value of the most likely (‘primary’) and other (‘secondary’) clusters were determined by conducting Monte Carlo replications of the data set, using the Poisson model, adjusted for household size (Kulldorff, 1997).

3. Results

The survey identified a total of 58 persons in the colony with diarrhoea, of whom 51 were permanent residents. The seven non-permanent residents were excluded from the study. The overall attack rate was 4.56%. The index case was identified as a 26-year-old male construction worker who commuted for work to Vellore town from the Kaniyambadi Harijan Colony. He had developed a diarrhoeal illness on 18 October 2004.

Figure 1 shows the epidemic curve of the outbreak. Two peaks were seen, 9 days and 14 days after onset of illness in the index case. The age and sex distribution of cases is shown in Table 1. All ages were affected. Overall, the age-specific attack rate was higher at the extremes of ages; however, this difference was not statistically significant (Table 1). There was one death, of an 80-year-old female, at an early stage of the outbreak. Attack rates at the extremes of age (lower 25th + upper 75th centile = 5.89%) were significantly higher than the middle 50th centile (3.14%; \( \chi^2 = 4.85, P = 0.03 \)). The attack rate of the upper 75th centile (5.69%) was not significantly different from the middle 50th centile (\( \chi^2 = 3.12, P = 0.08 \)), whilst the attack rates between the lower 25th centile (6.08%) and the middle 50th centile were significantly different (\( \chi^2 = 4.12, P = 0.04 \)). There was no difference in gender-specific attack rates (males = 4.44% vs. females = 4.67%; \( \chi^2 = 0.03, P = 0.86 \)).

Superimposition of rainfall on the epidemic curve (Figure 1) showed that the onset of illness in the first case coincided with the beginning of rainfall, and the following week marked the beginning of the first cluster of cases. Intermittent rainfall and continued occurrence of cases persisted for almost 4 weeks. At investigation, there was evidence of localised submersion of the water supply system, particularly of the pipes leading to the overhead tanks, through puddles of rain water mixed with soil in an area where people in the colony defecated. In addition, in many places the bases of taps were

![Figure 1](image.png)
Table 1  Age and sex distribution of the population in the colony and of cases with diarrhoeal disease, with age-specific attack rates and relative risk (95% CI) for each age group

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Population</th>
<th>Cases</th>
<th>Attack rate (%)</th>
<th>Relative risk (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>0—4</td>
<td>57</td>
<td>52</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5—14</td>
<td>98</td>
<td>110</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>15—44</td>
<td>277</td>
<td>292</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>45—59</td>
<td>69</td>
<td>65</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>≥60</td>
<td>39</td>
<td>59</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>540</td>
<td>578</td>
<td>24</td>
<td>27</td>
</tr>
</tbody>
</table>

The colony received an intermittent water supply from two bore wells approximately 500 m away, piped through two separate metal pipes (water mains) to independent overhead water tanks located in the north and south of the colony. The tanks supplied the eastern and western halves of the colony (Figure 2). Attack rates for each of the two tanks were 4.92% and 5.76%, respectively. This difference in the attack rates was not statistically significant ($\chi^2 = 0.33, P = 0.57$). The two tanks supplying water to the colony have a capacity of 30 000 l each. Prior to the outbreak, each tank had been treated with 120 g of bleaching powder every evening. During the outbreak, the amount of bleaching powder was increased by an additional 20 g per tank. It was the practice to hold the water overnight and to open the distribution valves in the morning. An even dispersal of bleaching powder during the epidemic was calculated possibly to result in a maximum chlorine concentration of 0.05—0.1 ppm (WHO, 1993), assuming that there was no chlorine demand.

A total of 33 water taps were distributed throughout the colony. The direction in which water travelled in these pipes from the tank to the taps is shown in Figure 2. All the pipes were subterranean, with many of the taps lower than the surface of the road, located in pits. In the western half

Figure 2  Water supply system, areas of contamination and spatial distribution of case and non-case households in the colony. Arrows show the direction of flow of water from the tanks to the taps. The water pipes running through a field contaminated with faeces (rectangle oriented from northwest to southeast) can be seen.

of the colony, the pipes ran parallel to the sewage channels. Some outflows from the area around the taps had an open communication with sewage channels made of mud or cement beside the road. There were no sewage channels in the eastern half of the colony. Puddles of sewage and household waste were observed beside the taps in this part of the colony. Residents cleaned utensils and washed clothes near the taps in both parts of the colony.

Information on the source of drinking water was available for 948 residents. Nine taps supplying 238 residents were found to have no cases, whilst attack rates for the remaining taps ranged from 2.17% to 17.65%. Both the eastern and western halves of the colony had taps with high attack rates. The RR and the attack rate increased with increasing distance from the tanks but were not statistically significant (individual data not presented). Analysis of other risk factors showed that very few people had history of travel outside of the colony or had eaten food outside the home (individual data not presented).

Cases were distributed throughout the colony. Using SaTScan, the most likely spatial cluster (12.813980 N, 79.133120 E) of seven case households (compared with an expected 2.30 case households), with a radius of 0.04 km, was identified at the northeastern part of the colony (log-likelihood ratio = 3.41, RR = 3.48). However, this was not statistically significant (P = 0.86).

During the general survey, faecal matter of human origin could be seen in many places in the colony, especially in the northwestern part, in the area shown in Figure 2 and indicated as a ‘faecal field’. The community living in the northern part of the colony, including the index case, used many areas surrounding the water mains for defecation. An open gutter ran parallel to the water mains for approximately half the distance between the colony and the bore wells. There was evidence of repair as well as multiple joints in the water mains, which ran parallel and crossed the gutter. In one area, the pipe had a joint beneath stagnant sewage that had collected after the rain.

Water for microbiological examination collected from the two tanks and five taps towards the end of the outbreak showed moderate to very high coliform counts (range 10/100 ml to >900/100 ml), suggestive of faecal contamination. The difference in microbial levels between the taps and the tanks was not statistically significant (Mann–Whitney U-test statistic = −1.206, P = 0.23). No vibrios were isolated from the water, but these samples were collected after increased chlorination following the outbreak, although none of the samples tested showed the presence of any residual chlorine.

4. Discussion

More than 150 years after John Snow removed the pump handle in London, outbreaks of cholera continue to be reported worldwide. Availability of potable drinking water for a large proportion of the Indian population is a major public health concern. Studies from urban India have often found piped water to be unfit for human consumption (Baveja et al., 1989; Brick et al., 2004; Dilawari et al., 1994).

Ageing subterranean pipelines with multiple breakages are a common phenomenon in India. In addition, in many parts of India where there is a piped water supply system, water pipes and sewage channels are laid beside each other, possibly for engineering convenience. Thus, mixing of sewage with water could potentially occur at multiple points. In a study of the Vellore municipal water supply, it was found that the level of contamination (coliform count) increased with increasing distance from the source, possibly owing to multiple sites of contamination. A comparatively newly developed area in Vellore, with more recently laid water supply lines, had the least contamination (Brick et al., 2004). Another study in Lagos, Nigeria, with a similar water supply network also had similar findings (Egwari and Aboaba, 2002). In our study, there was no significant clustering of case households, and risk was found to be uniformly distributed throughout the colony irrespective of the distance of the pipes from the tanks or bore wells, possibly owing to contamination occurring proximally in an area through which both the pipelines traversed.

Not all organisms found in contaminated drinking water may be pathogens. However, when any pathogen enters a water delivery system with a potential for causing an outbreak, there is a markedly increased likelihood of an outbreak (Chakraborty et al., 1981; Dilawari et al., 1994; Singh et al., 1995, 1998; Taneja et al., 2003). In most parts of India the water supply is intermittent, thereby increasing the risk of contamination owing to the negative suction pressure during the supply intervals. With rainfall, submergence of supply pipes in a contaminated environment increases the likelihood of contaminated water entering the pipe. This may have been the case in this outbreak where the number of cases suddenly increased following rainfall.

In our study, both parts of the colony had contaminated water supply systems. The outbreak appears to have resulted when a person with probable cholera (acquired outside the area) used the defecation area in the northwestern part of the colony through which both the water mains were channelled. During this and other investigations, it has often been observed that public land is used as defecation areas. It is also always public land where common water supply systems are laid. During this outbreak, the residents of the colony had not perceived that their risk behaviour could have contributed to the outbreak. Legislation preventing defecation in public places could be an important public health intervention, in addition to education of the community.

Repeated water surveys have been conducted in Vellore town, the closest municipality. Attempts to source drawings or maps of water lines from the municipal office have never been successful, as maps do not exist. A poorly regulated system allows everyone, including private telephone and cable operators, to dig up roads to suit their convenience. Indiscriminate digging can result in damage to water pipes as well as creating potholes where contaminated water could easily accumulate. The use of GIS maps in planning the layout of water lines, sewage and cables would help with better regulation and maintenance of water supply and sewage systems. These maps could identify vulnerable areas with potential for contamination and thereby help in better surveillance.

Chlorination of drinking water has been recommended as a standard intervention procedure in the control of diarrhoeal diseases. For effective control of cholera outbreaks, the WHO has recommended a residual chlorine content

of 0.5 ppm (WHO, 1993). However, the adequacy of these standards in the Indian context is debatable. In a study performed in southern India, V. cholerae could be grown from seeded tap water in which up to 1 ppm residual chlorine was present (Ramakrishna et al., 1996). In our study, the amount of bleaching powder added was found to be grossly inadequate even by the WHO standards. Adding inadequate amounts of bleaching powder possibly gives a false sense of security to the users, whilst the risk of contamination remains the same. It is important to note that cases continued to occur despite the intervention, and water contamination was documented 3 weeks after the institution of intervention measures. Additionally, water samples collected towards the latter part of the outbreak from taps in different parts of the colony showed high levels of contamination.

In rural areas in India, water disinfection relies on single-point chlorination. A study in Ecuador showed that central chlorination of the municipal water system was not sufficient in maintaining adequate free chlorine residuals at the peripheral distribution sites (Weber et al., 1994). Booster chlorination at different points of the water supply system may be a better option (Propato and Uber, 2004) and the use of spatial information would be a useful adjunct to the decision-making process. Point-of-use disinfection techniques are options that have also proved to be effective (Mintz et al., 1995; Quick et al., 1999) and may be applicable in India. Also in rural southern India, which receives plenty of sunshine throughout the year, solar water heating systems could be another option (Kang et al., 2006). Boiling of water, although a good option may not be a viable alternative in the long run because of the costs involved (Tumwine, 2005).

Limited access to sanitary latrines, indiscriminate defecation in unregulated areas through which the water mains run, inadequate chlorination of drinking water, poor maintenance of water pipes, parallel sewage and water channels, unhygienic practices such as washing clothes and cleaning utensils in places used for collecting drinking water, communication between taps and gutters, and rainfall during the time of the outbreak may all have contributed to this outbreak.

In this investigation, the use of GIS strengthened the findings that cases were uniformly distributed throughout the colony, with no particular clustering in any area. It also showed the proximity of faecal contamination and the water supply. GIS-drawn maps were useful when a PowerPoint presentation was done both for educating the community in the colony and to convey the message local health authorities of the urgent need for repair and maintenance of faulty pipelines. The presentation resulted in the release of funds for repairing the pipes. In addition, a drainage system was put in place in the section of the colony that had no drains.

Although quantifying the volume of water used per family and the extent of contamination of drinking water or the environment was not within the scope of this study, collection of such information may have been useful in determining why some households remained unaffected throughout the outbreak.

Interventions through legislation, health education, personal protection through point-of-use disinfection and minor engineering modifications such as elevating subterranean water supply pipes would reduce the risk of contamination of piped water and prevent diarrhoeal disease outbreaks.

Conflicts of interest statement

The authors have no conflicts of interest concerning the work reported in this paper. The investigation was carried out by a non-statutory service provider, whilst public health intervention was provided by the statutory service provider.

Authors’ contributions

All the authors contributed to the design of the study; RS, ATP and SM collected the data and performed the analysis and interpretation of the non-spatial data; RS, DS and MVR did the analysis and interpretation of the spatial data; GK conducted the microbiological analysis of the water samples; RS, GK and VB drafted the manuscript. All authors read and approved the final manuscript. RS and VB are guarantors of the paper.

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References


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