Indian J Med Res 129, March 2009, pp 233-241

Study of water supply & sanitation practices in India using geographic information systems: Some design & other considerations in a village setting

Srila Gopal, Rajiv Sarkar, Kalyan Banda, Jeyanthi Govindarajan, B.B. Harijan, M.B. Jeyakumar, Philip Mitta M.E. Sadanala, Tryphena Selwyn, C.R. Suresh, V.A. Thomas, Pethuru Devadason, Ranjit Kumar David Selvapandian, Gagandeep Kang* & Vinohar Balraj

*Departments of Community Health & *Gastrointestinal Sciences, Christian Medical College, Vellore, India*

Received April 17, 2008

***Background & objectives*: Availability of clean water and adequate sanitation facilities are of prime importance for limiting diarrhoeal diseases. We examined the water and sanitation facilities of a village in southern India using geographic information system (GIS) tools.**

***Methods*: Places of residence, water storage and distribution, sewage and places where people in the village defaecated were mapped and drinking water sources were tested for microbial contamination in Nelvoy village, Vellore district, Tamil Nadu.**

***Results*: Water in the village was found to be microbiologically unfit for consumption. Analysis using direct observations supplemented by GIS maps revealed poor planning, poor engineering design and lack of policing of the water distribution system causing possible contamination of drinking water from sewage at multiple sites.**

***Interpretation & conclusions*: Until appropriate engineering designs for water supply and sewage disposal to suit individual village needs are made available, point-of-use water disinfection methods could serve as an interim solution.**

Key words Geographic information systems - sanitation - sewage - water contamination -water storage

Safe water is one of the most important felt needs in public health in developing countries in the twenty first century[1]. The year 2005 marked the beginning of the "International Decade for Action: Water for Life" and renewed effort to achieve the Millennium Development Goal (MDG) to reduce by half the proportion of the world's population without sustainable access to safe drinking water and sanitation by 2015 [2]. It is estimated by World Health Organization (WHO) and United Nations International Children's Emergency Fund (UNICEF) that 1.1 billion people lack access to improved water supplies and 2.6 billion people lack adequate sanitation[3].

It has been estimated that diarrheal morbidity can be reduced by an average of 6-20 per cent with improvements in water supply and by 32 per cent with improvements in sanitation[4]. In India, approximately 72.7 per cent of the rural population does not use any method of water disinfection and 74 per cent have no sanitary toilets[5].

Open air defaecation, a common practice among villagers, may lead to contamination of the water supply system and result in outbreaks of diarrhoeal disease[6,7]. The practice of tethering animals close to human dwellings and the consequent proximity to animal faecal matter further enhances the risk of contamination of drinking water[8,9]. The key to providing microbiologically safe drinking water lies in understanding the various mechanisms by which water gets contaminated, and formulating interventions at critical points to decrease and prevent contamination of drinking water[10].

We have earlier studied the socio-cultural factors impacting water safety with the help of a knowledge, attitudes and practices survey on water handling and usage, sanitation and defaecation practices in a village in southern India using questionnaires and focus group discussions[11]. This study was carried out to describe the water supply and sewage distribution systems in relation to human and animal dwellings, their wastes, drinking water quality and sanitary practices in the same village in southern India. Geographic information system (GIS) tools were used to demonstrate spatial relationships for a clearer understanding of problems and possible solutions.

Material & Methods

Study area and population: The study was carried out in Nelvoy (12.82210710N, 79.13330370E), a village in the Kaniyambadi block of Vellore district in Tamil Nadu State, India. The village, with a total population of 1166 residents, is geographically divided into two parts, the 'Main village' where 41 per cent of the residents lived, and an area demarcated for the lower caste called the '*Harijan* colony' for 59 per cent of the residents. There were a total of 562 males and 604 females, with a male-female ratio of 1:1.07. The adult literacy rate was 83.7 per cent; and 21.3 per cent belonged to the low, 34.7 per cent to the middle and 44 per cent to the high socio-economic status (SES) (CHAD data; unpublished).

Spatial mapping and analysis: Streets, houses, water supply, garbage, sewage channels, functional toilets in the village and community defaecation areas in the surrounding fields were mapped using a hand-held global positioning system (GPS) receiver Garmin GPS V (GARMIN International Inc., Kansas, USA). The 'waypoints' and 'trackpoints' provided by the GPS were downloaded using GPS Utility 4.10.4 software (GPS Utility Ltd., Southampton, England). They were then converted to 'shapefiles' using ArcView GIS 3.3 software (Environmental Systems Research Inc., California, USA). The attributes were then layered to ascertain spatial relationships.

To identify any significant spatial clustering of dry or subterranean taps located in the village, the SaTScan 7.0.1 software (*http://www.satscan.org/*) was used. This software moves a circular window systematically over a geographic area to detect significant spatial clusters. The radius of the window may vary 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 included 50 per cent of the study region, allowing both small and large clusters to be detected[12]. Likelihood ratios were calculated and P value derived by conducting Monte-Carlo replications of the dataset using the Bernoulli model[13]. The 'wet' taps were considered as controls, and 'dry' and 'subterranean' taps respectively as cases.

Testing water quality: To ascertain the microbiological quality of drinking water, a total of 20 water samples, 10 from the households, 8 from individual taps and 2 from the tanks, were chosen randomly using a stratified random sampling technique (stratified by streets), and tested for presumptive and confirmed coliform counts using the most probable number technique[14] and for residual chlorine levels. The 'pump-driver' of the village was asked about chlorination practices.

Statistical analysis: Data were analyzed using SPSS version 12.0 for windows (SPSS Inc., Chicago, Illinois; 1989-2001) software. To test for differences in the contamination levels between the water samples obtained from the tanks, taps and the households, Kruskal-Wallis test was performed. Fisher's exact test was performed to test for difference in dry and subterranean taps between the 'Main village' and the '*Harijan* colony', using CLINSTAT [15] software.

Results

The village of Nelvoy had a total of 211 houses divided into two distinct geographic units based on the prevailing caste system - the '*Harijan* colony',

Fig. 1. Distribution of streets, houses, and "faecal fields" in Nelvoy village. The local health sub-centre and "Exnora" (a self-help organization to promote for environmental management, especially municipal solid-waster management) could be visualized inside the largest "faecal field".

comprising of 127 (60.19%) houses and the 'Main village' comprising of 84 (39.81%) houses (Fig. 1).

The water supply to the village was pumped from two separate bore wells to overhead water tanks, both of which were 9.14 m (30 ft) from the ground. A galvanized iron (GI) pipe connected the water tank outflow to a polyvinyl chloride (PVC) pipe at ground level. The overhead tank in the 'Main village' had a capacity of 60,000 l, while that in the '*Harijan* colony' was 30,000 l. Water was supplied to individual taps through subterranean pipes made of PVC up to a maximum distance of 370 m in the 'Main village', and 300 m in the '*Harijan* colony'.

Taps were located at varying intervals along the street and there were many places where taps were missing. Interviews with the 'pump driver' established that the water supply was intermittent and varied from two hours in the 'Main village' to half an hour in the '*Harijan* colony'. Some taps in the village that had no water during the two weeks of the survey were referred to as 'dry taps'. '*Harijan* colony' had a significantly larger number of 'dry taps' (14, 82.4%) compared to the 'Main village' (3, 17.6%) (P=0.008), and also a significantly larger number of subterranean taps [57 (98.3%) vs. 1 (1.7%) P<0.001)] (Fig. 2).

Clustering of dry taps (most likely spatial cluster of dry taps, observed = 12, expected = 5.32) was in the eastern part of the '*Harijan* colony' (12.821178 N, 79.134605 E), with a radius of 0.08 km (log-likelihood ratio = 8.36, P=0.02). There was also significant

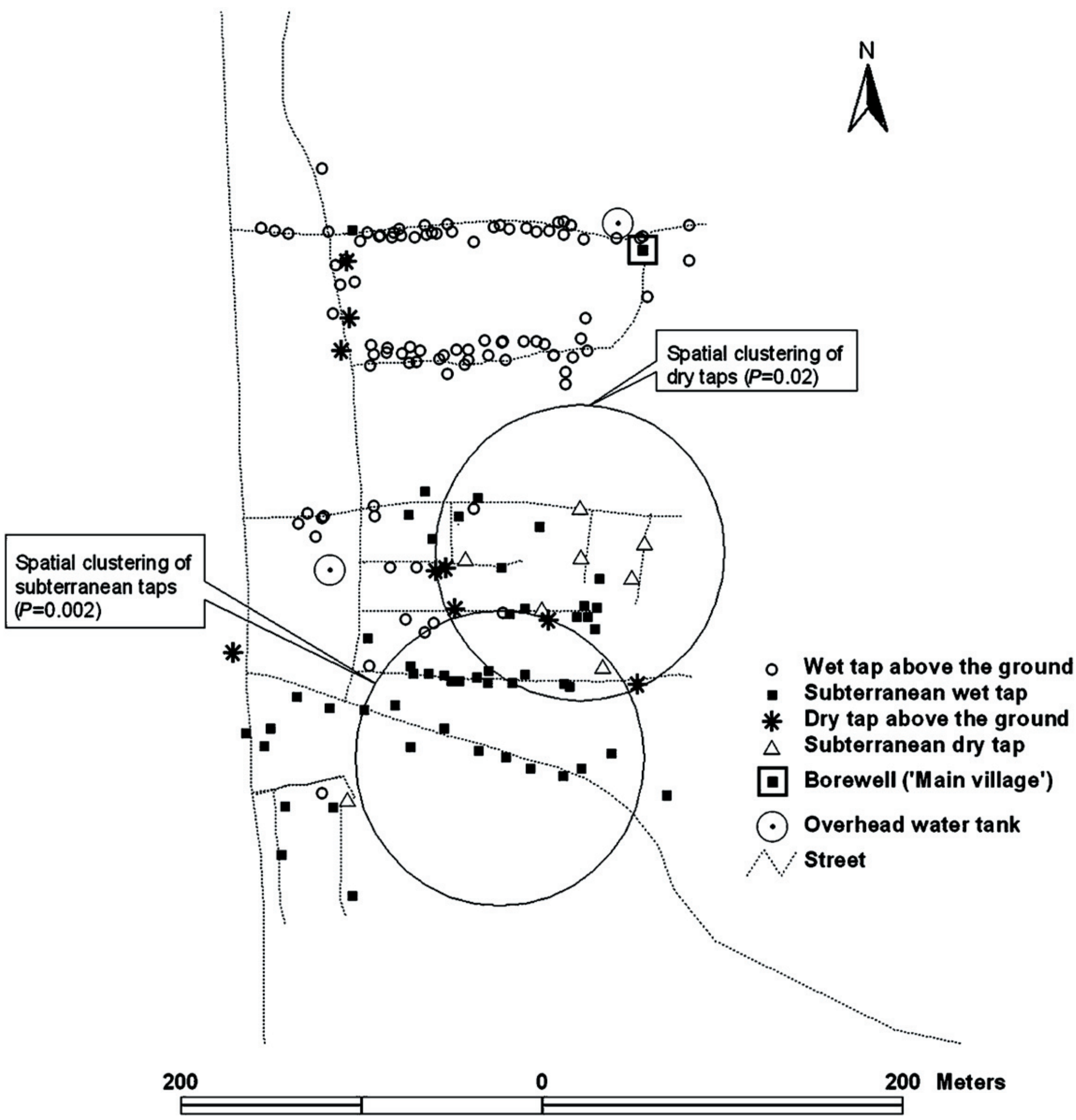

Fig. 2. Distribution of taps and tanks and borewell in Nelvoy village. Circles represent the spatial clustering of dry and subterranean taps. The borewell supplying the '*Harijan* colony' was located about 1.5 km to the west of the village.

spatial clustering of subterranean taps (observed = 24, expected = 17.32, log-likelihood ratio = 9.71, P=0.002) in the southern part of the 'colony' (12.820203 N, 79.134237 E), with a radius of 0.08 km.

The '*Harijan* colony' had an open sewer system, with sewage channels occupying about 0.3 m on the side of the street. The 'Main village' had localized collections of waste water and there was no organized sewage system. Animal faecal matter was interspersed around houses (where animals were tethered), and in the streets. Children were seen defaecating on the streets. Also, at certain points faeces were visible in the sewage drains and around the localized waste water collection spots. There was no system for collection and disposal of garbage. In certain places, garbage was inseparable from human and animal faeces.

Sewage from the entire village drained into a common open pond on the opposite side of the highway. Another sewage collection (pond) draining the *Harijan* colony was located within 20 m of the central water storage tank (Fig. 3). Layering of the environmental attributes showed close proximity of

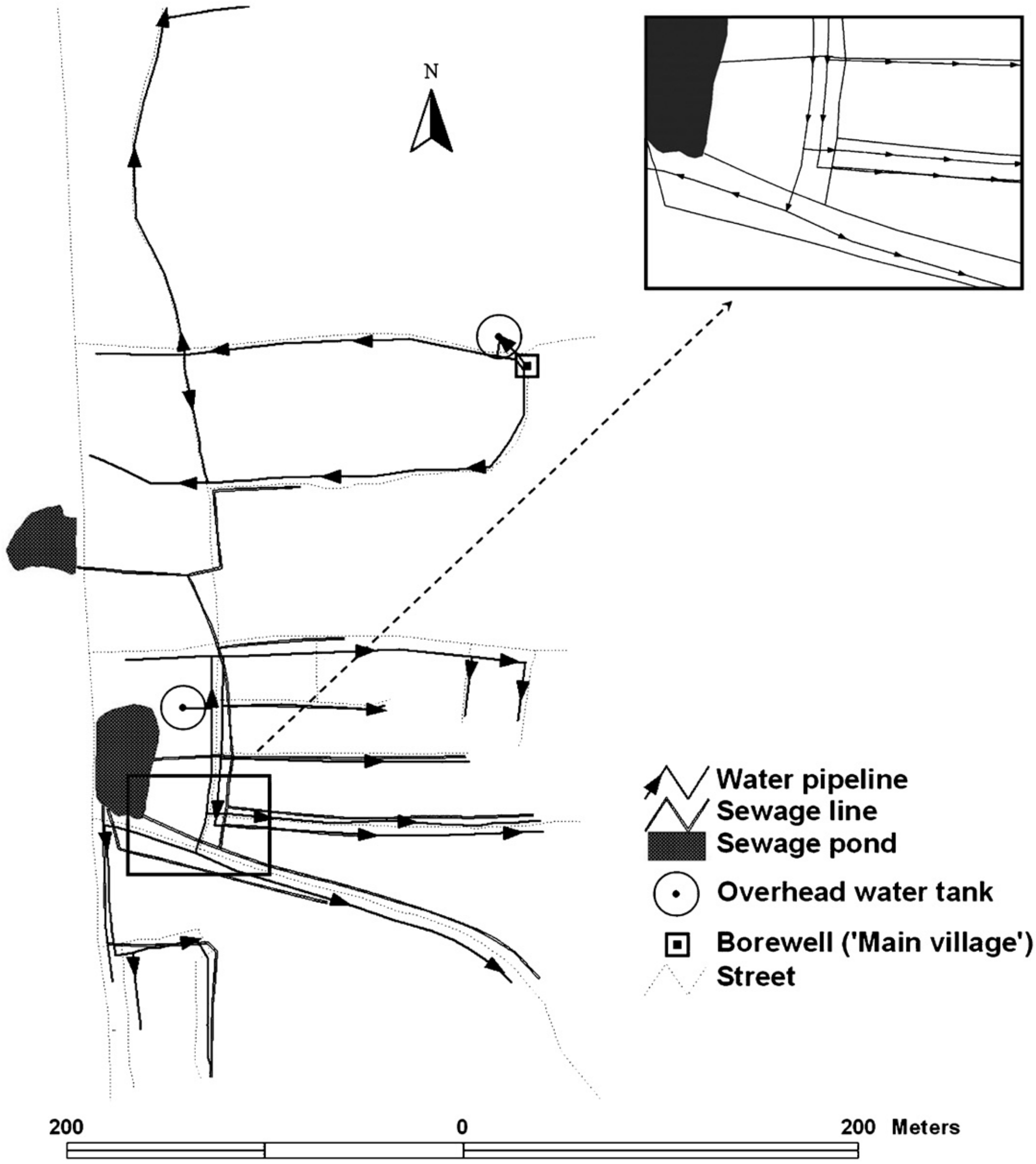

Fig. 3. Water pipelines and sewage channels in Nelvoy village. Inset shows the spatial proximity of water pipelines and sewage channels in '*Harijan* colony'.

water pipes to sewage, garbage and faecal matter. In most places, the water pipes were barely 5 m from the sewage channels and in some places they were less than 2 m away. There were places where sewage channels ran above the buried water pipes; while in other places, water supply pipes crossed the sewage channels (Fig. 3 inset).

Confirmed coliform counts in water samples from the two tanks were 24 and 54/100 ml respectively, whereas the counts in the eight taps ranged from 54 to >180/100 ml; nine of ten household samples showed coliform counts greater than 180/100 ml (Fig. 4). The difference in contamination levels between the household, tank and tap samples was statistically significant (Kruskal-Wallis test, P=0.004) (Table).

The water in the overhead tank of the 'Main village' was treated with bleaching powder once every fortnight, while in the '*Harijan* colony' it was added once a month. None of the 20 water samples tested had any residual chlorine. When asked about chlorination practices, residents complained that they did not like the smell of chlorine.

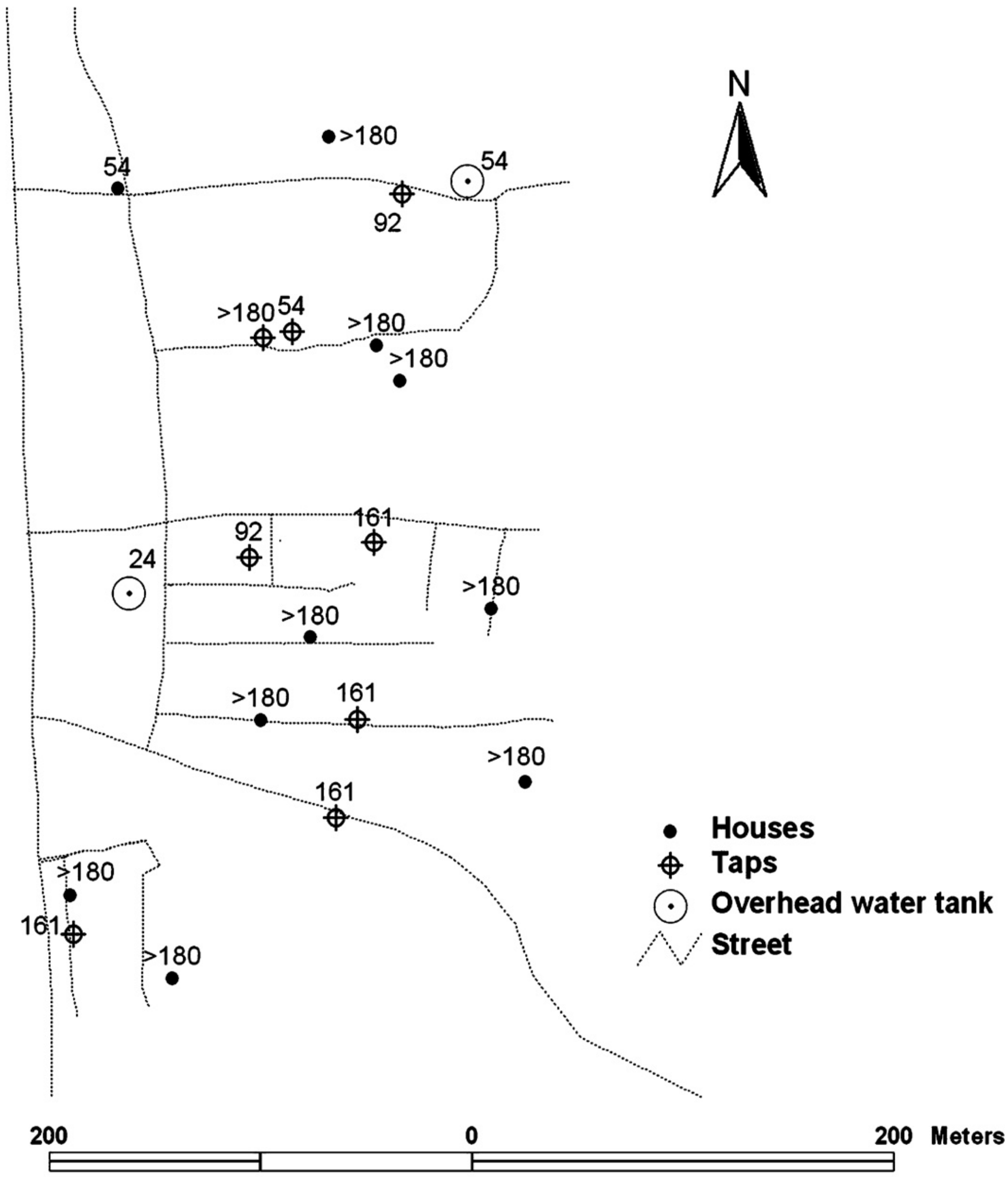

Fig. 4. Distribution of tanks, taps and houses from which water samples were obtained for presumptive coliform counts.

Nelvoy had 57 functional toilets. There was a public pay and use toilet/bath for women and children that was seldom used. Defaecating in the open fields was a common practice, both in the 'Main village' and in the '*Harijan* colony'. The three most frequented defaecation areas (polygons) surrounding the village were located within 100 m of the village (Fig. 1). There were different sites for defaecation for men and women. The largest defaecation area was on the opposite side of the village, across the highway and had an area of approximately 14466.69 sq m, with a perimeter of about 519.16 m. All defecation areas together comprised 61923.12 sq m while the settlement area was 73757.31 sq m. The ratio of the settlement to defaecation area was 1:0.84. The 'defaecation or faecal fields' were also located in close proximity to the drinking water sources and areas under cultivation.

Discussion

Provision of safe drinking water has been of primary concern in rural India[16,17]. Studies done in and around Vellore town, both in epidemic and endemic settings have found drinking water to be microbiologically contaminated and unfit for human

Table. Coliform counts of water samples obtained from the tanks, taps and houses in Nelvoy village

Sampling points	No. sampled	Coliform count (Mean ± SD) (MPN per 100 ml)
Overhead tanks	2	39.00 ± 21.23
Taps	8	132.75 ± 46.21
Houses	10	167.40 ± 39.85

Kruskall-Wallis test, P=0.004
MPN, most probable number

consumption[7,14,17-19]. In this study also, contamination of drinking water was evident from the high levels of coliforms present in water samples collected at various locations and was suggestive of contamination both at the source (overhead tanks) and also in the distribution taps and water stored in homes.

In Tamil Nadu, there are guidelines for provision of potable drinking water in villages and to ensure segregation of sewage and drinking water. This includes setting up a village level water and sanitation committee to formulate a master plan for sewage and drainage [20]. These guidelines state that water pipes should not go through sewage or should not be submerged in sewage at any point. However in this village, as with other villages, sewage channels were found to run parallel to water pipes and cross them at various junctions. Since these are open sewage channels, there is the possibility of sewage mixing with the piped water, especially as the water supply is intermittent, causing negative pressure in pipes. In order to ensure proper segregation of sewage and faeces from drinking water, alternate designs are needed. Elevating the water pipe at places where water lines cross sewage and covering the sewage channels at junctions are possible methods to minimize contact of sewage with drinking water.

The guidelines also specify the maximum permissible taps per tank (depending on its capacity) and prohibit people from lowering taps into pits (referred to as subterranean taps). At the distal end of '*Harijan* colony' a cluster of subterranean taps was seen inside dug pits, which was an indirect evidence of lower water pressure. This also resulted in sewage channels being at a higher level than the taps. After rain, entry of sewage through these taps was a distinct possibility.

Open air defaecation and the practice of tethering animals close to human dwellings contributed to the conversion of large areas of land in and around the village into 'defaecation or faecal fields'. In our study, animal and human faecal contamination of topsoil was evident on inspection of these areas. A mapping of these areas showed reservation of a substantial land area for this purpose, while sanitary toilets would require less land and serve to segregate faeces from water sources. These 'faecal fields' potentially put the village at risk of flooding with faecal material from surrounding areas during rains. In an adjoining village, a suspected outbreak of cholera was reported after heavy rain because of poorly maintained water supply pipes that ran through a faecal field[7]. Existing Tamil Nadu Water Supply and Drainage (TWAD) Board[20] guidelines specify that the public should not defaecate around the tanks and the taps, but is non-specific when it comes to defaecation in other places, not accounting for the fact that common defaecation areas are usually in the public land where the water supply pipes are laid.

The commonest form of disinfection in rural India is single-point chlorination, using bleaching powder. However, this may not be effective because of the possibility of multiple sites of contamination[21]. In this study village, the amount of chlorine added was inadequate by the WHO standards[22]. Water is pumped every day but the current TWAD Board[20] guidelines specify that chlorination should be done once a month, thus requiring modification. Alternative point-of-use disinfection methods such as solar water treatment[23,24] or point-of-use chlorination[25] and storage of water in narrow-mouthed vessels[26] need to be explored. Considering the contamination of all water samples at the household level, end-user disinfection is likely to be more effective in such settings[27]. However, such methods may not be sustainable over longer periods or may not be cost-effective in rural India[28].

The use of GIS tools to store information about a community with regard to their environment is a novel way to use this technology in public health[29,30]. GIS maps have an advantage over traditional hand drawn maps since it is possible to integrate environmental attributes such as slopes and soil into a single visual representation by the layering technique. In this study, most of the observations made were supplemented with GIS maps which were helpful in identifying potential risks.

In conclusion, poor planning and maintenance of the water supply system has led to inappropriate usage and over-exploitation of available resources, thereby causing contamination in the study village. The existing guidelines need to be modified. Proper measures should be formulated for periodic monitoring and stricter implementation of these guidelines, and policy makers should be sensitized.

Acknowledgment

Authors thank Dr Jayanth Devasundaram for his help with the GIS and spatial analysis of the data, Ms. Pearline Suganthy for statistical analysis of the data, and Ms. Sheela Roy for microbiological analysis of the water samples. Authors acknowledge the Community Health Department, Department of Gastrointestinal Sciences and Clinical Pharmacy, Christian Medical College, Vellore for their help in the study, and ESRI for providing the ArcView GIS software and Dr Mani M. Mani for providing us the Garmin GPS receivers. Authors also thank the people of Nelvoy village for their co-operation.

References

1. Sobsey MD, Bartram S. Water quality and health in the new millennium: the role of the World Health Organization Guidelines for Drinking-Water Quality. *Forum Nutr* 2003; *56* : 396-405.
2. WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation. Meeting the MDG drinking water and sanitation target: a mid-term assessment of progress. World Health Organization, Geneva and United Nations Childrens Fund, New York; 2004.
3. Moe CL, Rheingans RD. Global challenges in water, sanitation and health. *J Water Health* 2006; *4* (Suppl 1) : 41-57.
4. World Health Organization. Water Sanitation and Hygiene Links to Health Facts and Figures. Geneva, World Health Organization; 2004. Available from: *http://www.who.int/water_sanitation_health/factsfigures2005.pdf*, Accessed on November 14, 2007.
5. International Institute for Population Sciences (IIPS) and Macro International. National Family Health Survey (NFHS-3), 2005-06: India: Volume I, Mumbai: IIPS; 2007.
6. Bora D, Dhariwal AC, Jain DC, Sachdeva V, Vohra JG, Prakash RM, *et al*. *V. cholerae* O1 outbreak in remote villages of Shimla district, Himachal Pradesh, 1994. *J Commun Dis* 1997; *29* : 121-5.
7. Sarkar R, Prabhakar AT, Manickam S, Selvapandian D, Raghava MV, Kang G, *et al*. Epidemiological investigation of an outbreak of acute diarrhoeal disease using geographic information systems. *Trans R Soc Trop Med Hyg* 2007; *101* : 587-93.
8. Howe AD, Forster S, Morton S, Marshall R, Osbrn KS, Wright P, *et al*. *Cryptosporidium* oocysts in a water supply associated with a cryptosporidiosis outbreak. *Emerg Infect Dis* 2002; *8* : 619-24.
9. Licence K, Oates KR, Synge BA, Reid TM. An outbreak of *E. coli* O157 infection with evidence of spread from animals to man through contamination of a private water supply. *Epidemiol Infect* 2001; *126* : 135-8.
10. Trevett AF, Carter R, Tyrrel S. Water quality deterioration: a study of household drinking water quality in rural Honduras. *Int J Environ Health Res* 2004; *14* : 273-83.
11. Banda K, Sarkar R, Gopal S, Govindarajan J, Harijan BB, Jeyakumar MB, *et al*. Water handling, sanitation and defecation practices in rural southern India: a knowledge, attitude and practices study. *Trans R Soc Trop Med Hyg* 2007; *101* : 1124-30.
12. Kulldorff M, Nagarwalla N. Spatial disease clusters: detection and inference. *Stat Med* 1995; *14* : 799-810.
13. Kulldorff M. A spatial scan statistic. *Commun Statist Theor Meth* 1997; *26* : 1481-96.
14. Ramakrishna BS, Kang G, Rajan DP, Mathan M, Mathan VI. Isolation of *Vibrio cholerae* O139 from the drinking water supply during an epidemic of cholera. *Trop Med Int Health* 1996; *1* : 854-8.
15. Bland JM, 1996. A simple interactive statistical programme. Version dated 08.05.1996 ed. London, St. George's Hospital Medical School; 1996. Available from: *http://www-users.york.ac.uk/~mb55/soft/soft.htm*, accessed on November 14, 2007.
16. Bilas R, Singh RP. Rural water supply and the problem of health in village India, case of the Varanasi district. *Geogr Med* 1981; *11* : 65-85.
17. Kang G, Ramakrishna BS, Daniel J, Mathan M, Mathan VI. Epidemiological and laboratory investigations of outbreaks of diarrhoea in rural South India: implications for control of disease. *Epidemiol Infect* 2001; *127* : 107-12.
18. Brick T, Primrose B, Chandrasekhar R, Roy S, Muliyil J, Kang G. Water contamination in urban south India: household storage practices and their implications for water safety and enteric infections. *Int J Hyg Environ Health* 2004; *207* : 473-80.
19. Pai M, Kang G, Ramakrishna BS, Venkataraman A, Muliyil J. An epidemic of diarrhoea in south India caused by enteroaggregative *Escherichia coli*. *Indian J Med Res* 1997; *106* : 7-12.
20. Tamil Nadu Water Supply and Drainage (TWAD) Board. Guidelines for provision of water supply and hygiene for the village panchayat [*Book in Tamil*]. Northern Zone, Vellore, Tamil Nadu: Tamil Nadu Water Supply and Drainage Board, Communication and Human Resource Development Division; 2007.
21. Propato M, Uber JG. Vulnerability of water distribution systems to pathogen intrusion: how effective is a disinfectant residual? *Environ Sci Technol* 2004; *38* : 3713-22.
22. WHO. *Guidelines for cholera control*. Geneva: World Health Organization; 1993.
23. Kang G, Roy S, Balraj V. Appropriate technology for rural India - solar decontamination of water for emergency settings and small communities. *Trans R Soc Trop Med Hyg* 2006; *100* : 863-6.
24. Rose A, Roy S, Abraham V, Holmgren G, George K, Balraj V, *et al*. Solar disinfection of water for diarrhoeal prevention in southern India. *Arch Dis Child* 2006; *91* : 139-41.

25. Arnold BF, Colford JM Jr. Treating water with chlorine at point-of-use to improve water quality and reduce child diarrhea in developing countries: a systematic review and meta-analysis. *Am J Trop Med Hyg* 2007; *76* : 354-64.

26. Mintz ED, Reiff FM, Tauxe RV. Safe water treatment and storage in the home. A practical new strategy to prevent waterborne disease. *JAMA* 1995; *273* : 948-53.

27. Clasen T, Roberts I, Rabie T, Schmidt W, Cairncross S. Interventions to improve water quality for preventing diarrhoea. *Cochrane Database Syst Rev* 2006; *3* : CD004794.

28. Zwane AP, Kremer M. What works in fighting diarrheal diseases in developing countries? A critical review [working paper on the internet]. Boston: Center for International Development at Harvard University; 2007. Available from: *http://www.economics.harvard.edu/faculty/kremer/papers/wbro.pdf*, accessed on November 14, 2007.

29. Riner ME, Cunningham C, Johnson A. Public health education and practice using geographic information system technology. *Public Health Nurs* 2004; *21* : 57-65.

30. Scotch M, Parmanto B, Gadd CS, Sharma RK. Exploring the role of GIS during community health assessment problem solving: experiences of public health professionals. *Int J Health Geogr* 2006; *5* : 39. Available from: *http://www.ijhealthgeographics.com/content/ 5/1/39*. Accessed on November 14, 2007.

Reprint requests: Dr Vinohar Balraj, Professor of Community Health, Christian Medical College, Vellore 632 002, Tamil Nadu, India
e-mail: vinohar@cmcvellore.ac.in