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


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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. 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. 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.
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. 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.

Open air defaecation, a common practice among villagers, may lead to contamination of the water supply system and result in outbreaks of diarrhoeal disease. 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. 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.

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. 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. Likelihood ratios were calculated and P value derived by conducting Monte-Carlo replications of the dataset using the Bernoulli model. 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 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 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’,...
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 \( [57 (98.3\%) \text{ vs. } 1 (1.7\%) \ (P<0.001)] \) (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
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...
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.
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\textsuperscript{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
In conclusion, poor planning and maintenance of the water supply system has led to inappropriate usage and over-exploitation of available resources,

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. 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.

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References


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