Water-safety plans for piped supplies with limited data – a case study from India

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Problems arise implementing WSPs in many towns where data on the piped network is limited. Risk mapping can be a useful tool to overcome this and identify points where risk is particularly high. It uses local engineers' knowledge to assess physical hazards and the vulnerability of the pipework and uses proxies for the susceptibility of the population to disease.

The key to the implementation of a successful WSP is gaining a thorough understanding of the entire water-supply system from the catchment to the consumer. However, in Guntur, Andhra Pradesh, India, as in many towns with piped systems in developing countries, a disruptive colonial history combined with unmonitored supply extensions by foreign contractors has meant that detailed engineering maps for piped water supplies are unavailable. This lack of data can be overcome, however, by a process of risk mapping.

Risk mapping

Maps are an ideal way to present risk, as risk data often have numerous variables. These maps do not have to be designed using computer software such as geographical information systems – paper copy maps may be used – but computer software (AUTOCAD) was used in this project because of the availability of computing skills among staff at the project site in Andhra Pradesh.

The first step in the development of the risk maps involved finding other available maps. A copy of the major road network was obtained from the Public Health Engineering Department and Guntur Municipal Corporation. By reference to the road network, the primary and secondary pipe network was identified and marked on the map. Using this map as a platform, the key infrastructural points of the system and hydraulic supply zones were identified. Figure 1 and Box 1 describe each stage of the Guntur system.

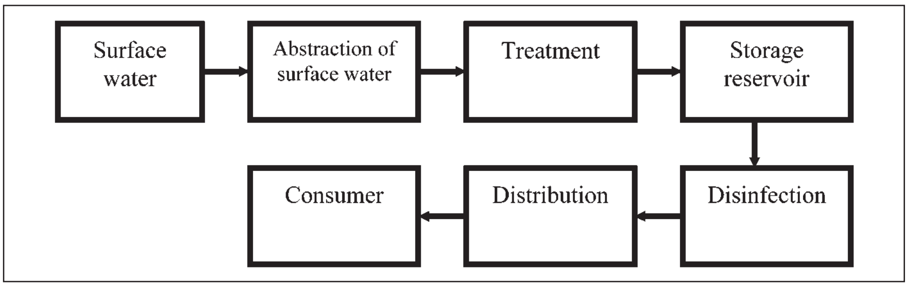

Figure 1 Guntur's water supply

In sections of the piped-water supply there were minimal data, and here operations engineers and tap inspectors provided detailed 'local knowledge' of where each of the main infrastructure points was located on the base map. All operations engineers and tap inspectors were interviewed individually and asked to mark on the base map the primary trunk mains, secondary service mains and other major items of infrastructure within the system, such as:

- treatment works
- service reservoirs
- booster stations
- major valves.

Following the development of the base map, the supply pattern or hydraulic zones were identified. These were primarily based on local knowledge of permanently closed valves. The supply zones were mapped from the two Guntur water-treatment works (Takkellapadu and Jagarlamudi) to the service reservoirs. The response from each 'expert' was mapped as a layer on an AUTOCAD 2000 file and these are outlined in Figure 2.

The concept of risk

Having located the principal infrastructure and ten supply zones, critical control points were identified within each supply zone that would form the basis for system monitoring. A method was

Box 1. Guntur's water-supply system

The Guntur system is fed from the River Krishna. It has two treatment works, which use sedimentation, filtration and disinfection (chlorination). Guntur's water supply is an intermittent system: water is distributed to the consumers for only one hour per day from the tank. The city is divided into ten zones and the water is distributed through a 600 km pipe network.

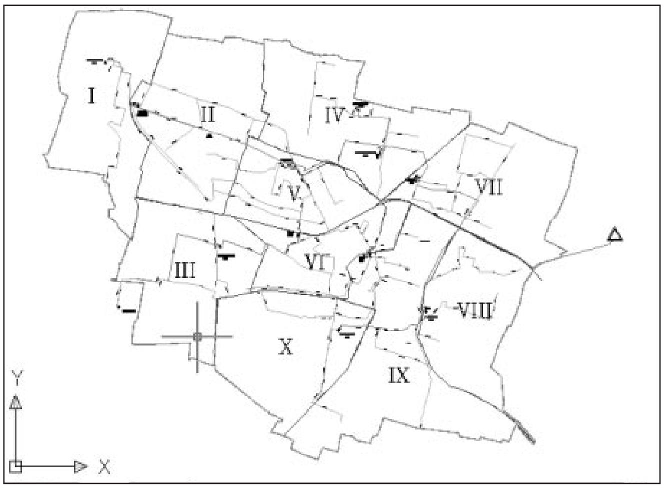

Figure 2. The water-supply zones, Guntur

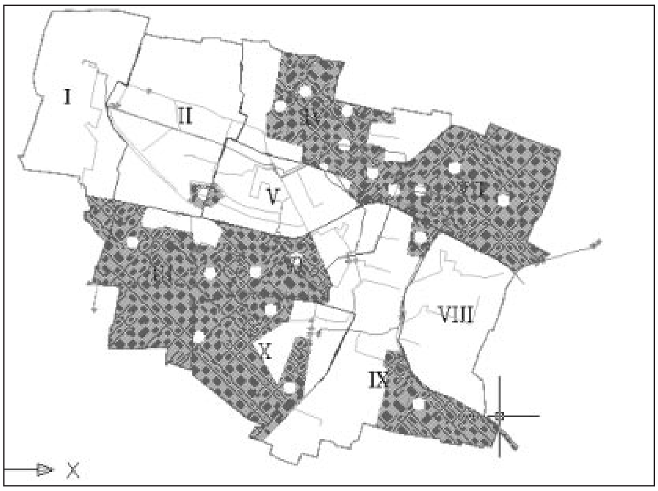

Figure 3 The marked risk areas are those with greatest hazard, pipe vulnerability and socio-economic susceptibility.

developed that relied on minimal available data where the concept of risk was defined by the hazards and vulnerability associated with the system. In line with new definitions of risk,[1] the approach to controlling water quality in distribution systems takes into account both the vulnerability and hazard events affecting the water supply as well as the susceptibility of the users (e.g. those with lower incomes usually have higher health burdens).

Hazard assessment

To assess the hazards in the system, field assessments of sanitary risks were undertaken in identified areas using system-specific quantitative tools, including sanitary inspections. These were designed according to the WHO *Guidelines*[2] which include the suggestions for individual sanitary inspection forms for different technologies. The sanitary inspections assessed the proximity of pipes to physical hazards (e.g. sewers or low-lying areas) and provided an estimate of the proximity of the pipe to areas of high faecal loading. Sanitary surveys were accompanied by water-quality testing of selected physico-chemical parameters. These included:

- free residual chlorine – to assess residual disinfectant throughout the piped network
- total residual chlorine – to assess whether chlorination at the works had been carried out
- pH – to measure the acceptable range for chlorination
- turbidity – to assess the ingress of organic material and the impact of turbidity on free chlorine residual or aesthetic quality (colour).

The information gained on hazards affecting each individual inspection point was then projected onto stretches of pipe both up and down from the inspection points on a separate map layer.

Due to the limited availability of sanitation data, population density was used as a surrogate for faecal loading (i.e. the more people, the more faeces in the environment). Census data were collected from the town-planning department for the year 2001 to calculate the population density, and this was then categorized into very high, high, medium and low population density. Points located within areas with a high population density were perceived to be at greater risk. For comparison, the data were fed into a semi-qualitative risk matrix to allow ranking of the hazard for each geographical area.

Vulnerability assessment

Assessment of the physical vulnerability of the distribution system was also limited as the pipes are underground. Based on expert judgement, a multivariate definition of vulnerability was developed that considered the factors of pipe age, material, diameter and length. For each factor a semi-qualitative risk value was assigned to help prioritize the risk associated with each pipe section.[1] Examples of pipe material and age are outlined below.

Pipe material. A survey of the Guntur water distribution system by local operations engineers revealed that the system comprises four pipe materials: reinforced cement concrete (RCC), asbestos cement (AC), cast iron (CI) and polyvinyl chloride (PVC). A high-, medium- or low-risk ranking was given to each material, based on data relating to failure, chlorine consumption of the material and economy of the pipe material. The mapping of the different sections of pipe material in the supply was carried out by walking the critical sections of the supply in the field.

Pipe age. In Guntur, the network is composed of approximately 60% RCC, 20% CI, 10% AC and 10% PVC.[3] The original primary main from Takkellapadu treatment plant was installed between 1980 and 1983 and was made of reinforced cement concrete; one other primary main from Jagarlamudi treatment plant was installed between 1950 and 1952, and was made of cast iron. A detailed study was undertaken that involved mapping sections of the distribution by age of pipe laid. Based on this it was concluded that RCC pipes had a higher risk than the CI pipes, because the contractors had used lower-quality RCC pipes and the installation method adopted was poor. The higher-quality cast-iron pipes laid by the British were in good condition but because of the higher cost of cast iron, Guntur Municipal Corporation had subsequently chosen the RCC pipes in the more recent sections. Taking these points into account, risk scorings were given to

Table 1 Vulnerability ranking table – showing data for just one inspection point

	Pipe attributes (PIPE NO: 66)								Sanitary inspection data		No. of high-risk ranks	Final vulnerabiity score
	Material	Risk rank	Diameter (mm)	Risk rank	Length (m)	Risk rank	Year of installation	Risk rank	Leakage	Risk rank	Total 'H'	
Valve box (4VB57) Sharada Nagar	RCC	*H*	60	*L*	498	*H*	1983	*H*	High	*H*	4 (high risk)	High

each section of the supply based on observations regarding pipe age.

Vulnerability scoring. To estimate the overall vulnerability for each inspection point within the supply, the sub-variables relating to the pipe attributes and the sanitary inspection data were combined in a semi-qualitative risk matrix, which gave an overall vulnerability rank (see Table 1). This rank was then used to establish the static vulnerability within the piped network at each inspection point.

Susceptibility

Based on assumptions that health burdens are highest in low-income communities because they are more susceptible to disease, Guntur's population was categorized into four socio-economic groups: very low income, low income, medium income and high income. These were assessed quantitatively by observing the house type and roof material in each of the supply zones from the top of the elevated service reservoir. A comprehensive check list and sketch map was developed to display various socio-economic levels.

Risk-point selection

Based on the assessment of the hazard, vulnerability and susceptibility of those using the supply, 62 points were identified as high-risk points (see Figure 3). The risk to the supply was further assessed using selected microbial indicator bacteria: *E.coli* and *Enterococcus faecalis*. Samples were taken for analysis of *E. coli* and *Enterococcus faecalis* within the treatment works and throughout the distribution systems.

Based on these results, water safety plans were developed for each inspection point. The plan identified a range of hazard events and provided clear control measures to prevent the hazard event from occurring, as well as critical limits for each of the measures. Corrective actions were then proposed for each control measure to be put into effect when an increase of risk was noted at a control point.

The secondary main, Guntur

Conclusions

The research suggested that insufficient data do not limit the development of WSPs. Using a multivariate principle of risk that relies strongly on expert judgement, a number of risk points can be identified in piped systems. The research concluded that WSPs are an effective method of 'getting to know' your system.

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