Journal of Water Supply: Research and Technology—AQUA | 59.5 | 2010

Practical Paper

Risk assessment study for water supply network using GIS

Aabha Sargaonkar, Shweta Nema, Apurba Gupta and Achintyakumar Sengupta

ABSTRACT

In recent years, contamination of water in water distribution systems (WDS) has been recognized as a major cause of waterborne diseases. Owing to old and deteriorated pipes, and the presence of pollution sources in contact with the supply line, water boards often decide to replace the network in the interests of public health. This being a cost-intensive and time-consuming programme, decision makers need a basis for phase-wise investment planning. In view of this, Integrated Risk Assessment of Water Distribution System (IRA-WDS) for the supply network of Adikmet Subzone-I in Hyderabad, India, was undertaken. GIS maps were prepared for the water supply network, sewer network, open drains, soil and groundwater table at 1:2,200 scale and 'pipe condition assessment' and identification of 'contaminant ingress' locations were performed using IRA-WDS. Findings indicated 18 pipes in 'very bad' and 'bad' condition in the entire network. 'High risk' of contamination was exhibited in 20 locations, suggesting the need for rehabilitation of only 2 to 3% of pipes in the initial phase.

Key words | GIS, risk assessment, water distribution system

Aabha Sargaonkar (corresponding author)
Shweta Nema
Apurba Gupta
Environmental Systems Design and Modelling Division,
National Environmental Engineering Research Institute, Nehru Marg,
Nagpur 440 020,
India
Tel.: +91 0712-2249886-88 (ext. 358)
Fax: +91 0712-2249900
E-mail: *ap_sargaonkar@neeri.res.in*

Achintyakumar Sengupta
WHO, India Country Office,
110011 India
E-mail: *Senguptaak@searo.who.int*

INTRODUCTION

A water distribution system (WDS) is expected to provide a continuous safe water supply to the urban population. However, because of unaccounted for water (UFW) arising from leakages and technical losses, which amounts to around 40 to 60% in developing countries (Ardakanian & Ghazali 2003; Çakmakcı *et al.* 2007) and 15% in developed countries (UNEP 2006), water supply in the WDS is often intermittent. This makes the system highly vulnerable to contaminant intrusion.

WDSs in direct contact with pollution sources (e.g. open drains, foul water bodies, broken sewers) or a contaminant zone (CZ) formed in the soil, have been recognized as a major cause of outbreaks of waterborne diseases (Clark *et al.* 1993; Geldreich 1996; Vairavamoorthy *et al.* 2006). In this context, significant infrastructure improvement has been identified in many countries to meet health-based targets (Clark *et al.* 2002). In India, Hyderabad Metro Water Supply and Sewerage Board (HMWS&SB) also had plans for complete rehabilitation of an old supply network of Reinforced Cement Concrete (RCC) and Asbestos Cement (AC) pipes in Adikmet Subzone-I in Hyderabad. The task being time-consuming and cost-intensive, a well-planned, phase-wise approach was needed. This paper presents a modelling study attempting to identify the most critical pipes in 'Bad' condition and under 'High risk' of contaminant intrusion to support decision making.

doi: 10.2166/aqua.2010.090

OVERVIEW OF IRA-WDS

Integrated Risk Assessment of Water Distribution System (IRA-WDS) is a spatial decision support system (SDSS) integrated in Arcview software (Vairavamoorthy *et al.* 2006, 2007) with the following three modules (Figure 1(a)):

- Contaminant ingress model (CIM) which predicts the 'hazard' (HA_k) in the system; i.e. transport of pollutant from CZ towards the pipe using Green-Ampts model and Darcy's Law.
- Pipe condition assessment (PCA) model, which predicts 'vulnerability' (VU_k) of the pipe to contaminant intrusion based on 'Fuzzy' AHP approach with 20 pipe indicator parameters (Figure 1(b)). The final indicator PCA index or PCA rank is used to classify the pipes by their relative condition from 'very bad' to 'very good'.

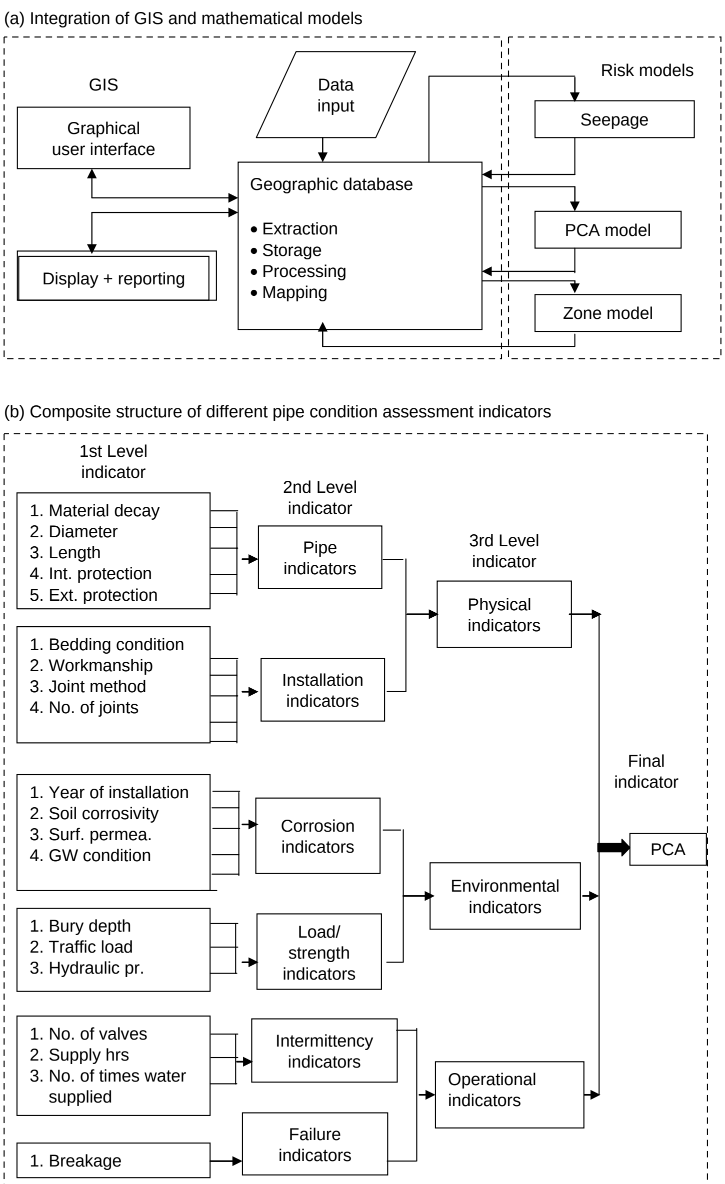

Figure 1 | Overview of IRA-WDS; (a) integration of GIS and mathematical models; (b) composite structure of different pipe condition assessment indicators (source: Vairavamoorthy *et al.* 2006).

- Risk assessment model (RAM) combines the predictions of 'hazard' and 'vulnerability' using multi-criteria decision making (MCDM) technique and produces a risk index (RI) by weighted linear combination as:

$$RI = (w_h HA_k) + (w_v VU_k), \quad k = 1, 2, \ldots N_c \tag{1}$$

where, w_h is weight for hazard agent, w_v is weight for vulnerability of pipe and N_c is no. of pipes.

RISK ASSESSMENT OF WATER SUPPLY NETWORK

Supply network

The study area of 1.66 km^2 lies between 17°23′31′ and 17°24′24′N latitude and 78°30′38′ and 78°31′42′E longitude. Water supply for about 4,900 service connections in the study area is continuous. Peak flow in the supply main remains at 2,644 $m^3 h^{-1}$ and the supply pressure is about 1.0 kg cm^{-2}. Existing distribution mains are of reinforced cement concrete (RCC) laid in 1975, asbestos cement (AC) in 1978, cast iron (CI) in 1996 and ductile iron (DI) in 2005. The district metering area (DMA) concept has been implemented and details of system input, authorized consumption, water loss, leakage in transmission and distribution mains are maintained as part of the 'best practice' standard approach in water audit (Farley & Trow 2003).

GIS mapping and field survey

For GIS mapping, AutoCAD maps were obtained from the Central Design Cell of HMWS&SB. Different layers of network for water supply, sewer, storm water drains, open drains and roads were extracted in ArcMap 9.2 (ESRI 2007). Maps at 1:2,200 scale were georeferenced using projected coordinate system WGS_1984 UTM Zone 44N Transverse Mercator Projection.

Field visits were made to verify the location of open drains, foul water bodies and slum areas given on the maps and discussions were held with local authorities for correct GIS mapping. Network information on defunct lines or replaced pipes was updated. Analysis of soil samples from the study area indicated the soil type as gravelly sand, brownish silty sand, greyish silty sand and dark brownish silty sand, with saturated hydraulic conductivity varying from 0.06 to 1.36 cm h^{-1} and bulk density 1.65 to 2.0 g cm^{-3}. Similarly, groundwater table (GWT) data monitored by HMWS&SB was used in GIS mapping.

Model application

Operation and maintenance data was obtained from the water board and analysed for model parameter estimation as given below:

Analysis of hourly pressure data monitored at 11 pressure gauge locations for one-month duration indicated a drop in pressure from service reservoir to end user. Based on this drop, 'pressure category' for various pipes was

Table 1 | Statistics of pipe condition assessment and risk assessment study

PCA rank	PCA index	Pipe condition	No. of pipes	%
1	0	Very bad	3	0.32
2	0–0.252	Bad	15	1.61
3	0.50–0.58	Medium	293	31.57
4	0.71–0.84	Good	327	35.23
5	0.92–1.0	Very good	290	31.25
Risk rank	**Risk index**	**Risk of contamination**	**No. of pipes**	**%**
2	0.3	Very high	3	0.32
3	0.45–0.54	High	17	1.83
4	0.63–0.82	Medium	490	52.8
5	0.86–1.0	Low	418	45.04

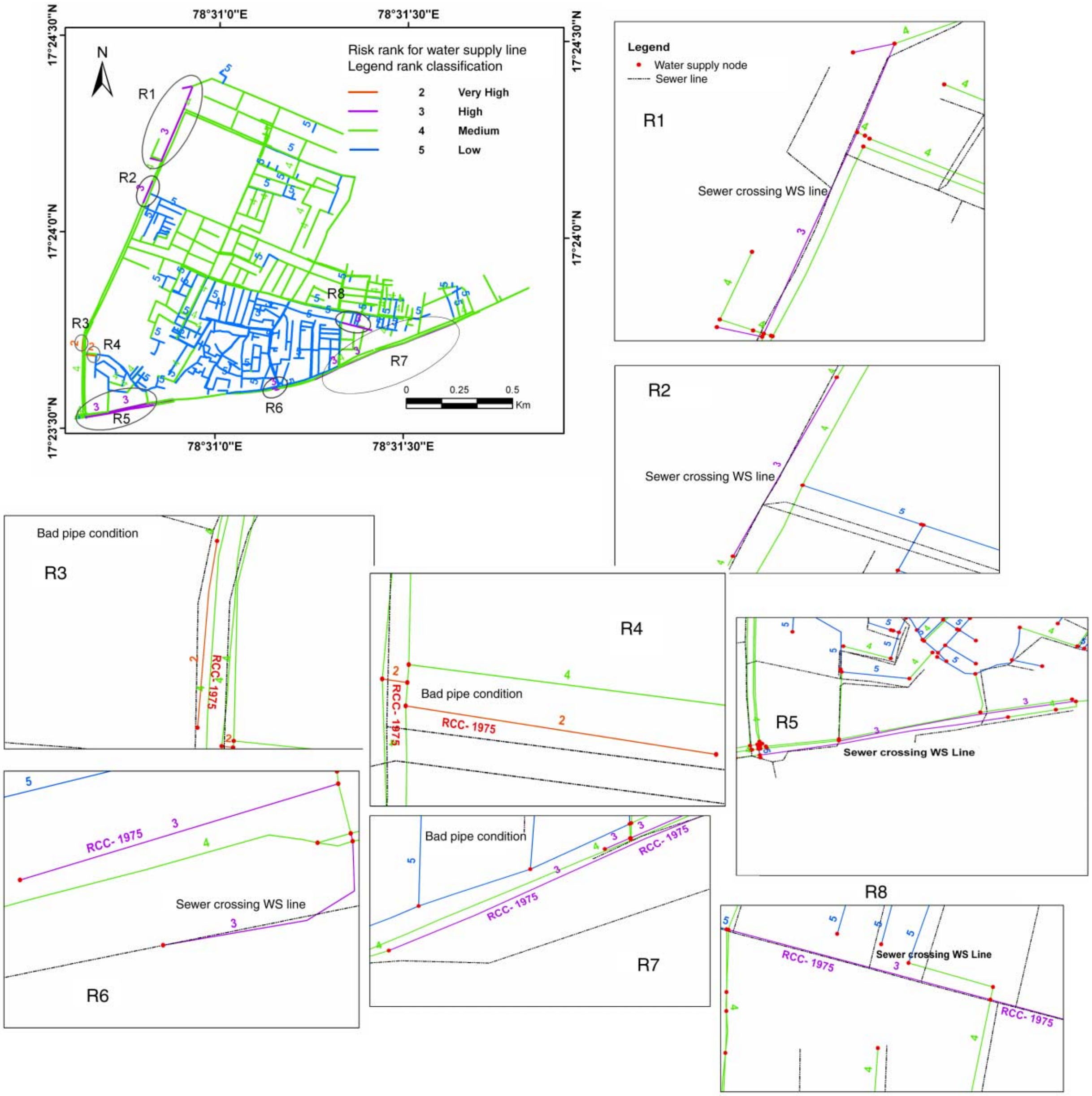

Figure 2 | Risk map of WDS and high risk points in Adikmet Sub-zone –I.

defined as 'low', 'medium' and 'high' for average pressure in the range 0.07 to 0.38 $kg\,cm^{-2}$, 0.38 to 0.76 $kg\,cm^{-2}$ and 0.76 to 1 $kg\,cm^{-2}$, respectively. Similarly, pipe breaks and burst frequency was determined as a function of traffic, pipe diameter and supply pressure. Traffic density was defined as 'busy', 'medium' and 'quiet' along major, minor and slum area roads, respectively; and distribution of pipes according to diameter was considered to define break frequency of 0, 1 or 2 per year so that total number of breaks was 720 as recorded by authorities.

Network statistics shows 427 RCC pipes (age 32 years), 13 AC pipes (29 years), 285 CI pipes (11 years) and 203 DI pipes (2 years). Considering CI and DI pipes as more prone to corrosion, leakage rate was estimated as a function of pipe age, corrosive/non-corrosive pipe material, and traffic along the road so that total leakage in the system approximates to 60% as recorded by authorities (4.64 million litres per day of unbilled supply and 8.7 million litres per day leakage).

The following GIS maps and estimated parameters formed the input for application of IRA-WDS:

- Line shape file of water distribution network and point shape file of nodes.
- Line shape file of sewer network and point shape file of nodes.
- Line shape file of canals/open drains and point shape file of nodes.
- Polygon shape files for groundwater table and soil type.

CIM identified the possible sites of contaminant ingress in the WDS, whereas the PCA model provided assessment of pipe condition. Higher weight (0.7) to 'vulnerability' was used to estimate RI in view of the old pipe network in the study area.

RESULTS AND DISCUSSION

The statistics obtained from the PCA model and RAM are presented in Table 1. Based on model results the following guidelines were delineated for rehabilitation:

- Replace only 18 pipes in 'Bad' and 'Very bad' condition in the initial phase
- 32% pipes in 'Medium' condition may be maintained by regular monitoring
- 66% pipes in 'Good' and 'Very good' condition may not need replacement at all.

GIS-mapping of 'High risk' areas (R1 to R8) encompass all 20 critical points where, either pipe condition is bad or pipe is in direct contact with pollution source (Figure 2). The exact location of critical points and the cause of contaminant ingress can be seen from zoom-level maps in GIS (Figure 2). It is necessary to provide internal and external protection with good workmanship and bedding condition to these pipes to prevent deterioration and contaminant ingress.

The study indicates the importance of record keeping by water boards: for example, records of pipe breaks or bursts with exact spatial location are rarely available. Infrastructure maps, records of system performance, and operation and maintenance data should be computerized for application of SDSS.

CONCLUSION

- A proactive approach for monitoring, maintenance and rehabilitation can prevent complete damage to a network over a period of time and ensure sustainable output from the water distribution system to meet health-based targets.
- Application of modern tools such as IRA-WDS helps to identify the exact location of contaminant ingress in underground WDSs. This can form the basis for decision making in phase-wise investment planning.

ACKNOWLEDGEMENTS

The authors are thankful to the director of NEERI for the encouragement to undertake the work and kind permission to publish this article. Consistent support during the project from Ravindra Rao, Sr Scientist, NEERI Zonal Lab, Hyderabad, and assistance from Sanjay Raut in GIS mapping are acknowledged with thanks. Financial support was received from USEPA /WHO, and HMWS&SB contributed in the execution of activity including field work.

REFERENCES

Ardakanian, R. & Ghazali, A. 2003 Pressure–Leakage Relation in Urban Water Distribution Systems, *Proceedings of ASCE International Conference on Pipeline Engineering and Construction, Baltimore, Maryland, July 13–16, 2003*.

Çakmakcı, M., Uyak, V., Öztürk, İ., Aydın, A. F., Soyer, E. & Akça, L. 2007 The Dimension and Significance of Water Losses in Turkey. Available at: http://www.waterloss2007.com/pdf_vortraege/Dienstag/B5-2.pdf (accessed 26 March 2010).

Clark, R. M., Goodrich, J. A. & Wymer, L. J. 1993 Effect of the distribution system on drinking water quality. *J. Water Suppl. Res. Technol.–AQUA* **42**(1), 30–38.

Clark, R. M., Sivaganesan, M., Selvakumar, A. & Sethi, V. 2002 Cost models for water supply distribution systems. *J. Water Resour. Plann. Manage.* **128**(5), 312–321.

ESRI 2007 ArcMap 9.2: A GIS Software. ESRI, Redlands, California.

Farley, M. & Trow, S. 2003 *A Practitioner's Guide to Assessment, Monitoring and Control*. IWA, London.

Geldreich, E. E. 1996 *Microbial Quality of Water Supply in Distribution Systems, Intrusion into the Distribution System*. Lewis Publishers, Boca Raton, Florida.

UNEP 2006 United Nations Environment Programme official website *Freshwater in Europe* http://www.grid.unep.ch/product/publication/freshwater_europe/consumption.php (accessed 26 March 2010).

Vairavamoorthy, K., Gorantiwar, S., Yan, J., Galgale, H., Mohamed-Mansoor, M. A. & Mohan, S. 2006 *Risk Assessment of Contaminant Intrusion into Water Distribution Systems, Water Safety Plans: Book 3*. Water Engineering and Development Centre, Loughborough University, UK.

Vairavamoorthy, K., Yan, J., Galgale, H. & Gorantiwar, S. 2007 IRA-WDS: a GIS-based risk analysis tool for water distribution systems. *J. Environ. Model. Softw.* **22**, 951–965.

First received 25 August 2009; accepted in revised form 25 February 2010