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Study the variability of water quality in a large distribution network

MD MARUF MORTULA*,
KAZI PARVEZ FATTAH
AND TARIG ALI

Civil Engineering Department,
The American University of Sharjah,
P.O. Box 26666, Sharjah, UAE
E-mail: mmortula@aus.edu
E -mail: kfattah@aus.edu
E-mail: atarig@aus.edu

ABSTRACT

Purpose: Maintaining a healthy water distribution infrastructure is the key to providing good quality services to the consumers for long period of time. Maintaining the integrity of the infrastructure is not possible without appropriate management of water quality throughout the water distribution system. Water distribution network in the city of Sharjah, UAE is facing one such challenge. Due to its large and diverse network characteristics, understanding the water quality pattern is critical to appropriate management. The objective of this paper was to study the variability of the water quality parameters in Sharjah water distribution network.

Methodology: Water quality monitoring data was collected from 46 different locations throughout the distribution network within Sharjah Water Electricity Authority (SEWA). Several water quality parameters were monitored including pH, Electrical Conductivity (EC), residual chlorine, iron and fluoride. Graphical and Geographic Information Systems (GIS) based analysis was conducted on the variability of water quality parameters throughout the distribution network.

*Corresponding author

Findings: The results indicated that the old part of the city is more venerable to water quality degradation than the new distribution network. Even though all the water quality parameters were within the limits set by the government, there are sections of distribution network that can be maintained with priority to ensure sustainable infrastructure.

Originality/Value: This study provides an important understanding of the variability of water quality through SEWA water distribution network. Hence, the study revealed the sections of the distribution network that needs to be managed for sustainable development for the city of Sharjah

Keywords: water distribution network; water quality; infrastructure integrity; sustainability; spatial variability; infrastructure management.

INTRODUCTION

A properly maintained water distribution system is critical in delivering safe water to the consumers (Furnass et al., 2013). Even though water treatment plants produce good quality water, the role of water distribution system has received a lot of scrutiny in the recent years. It is especially true for a large water distribution network where the interrelations between the distribution infrastructure and water quality are often very complex. Understanding the relationship is important not only for ensuring good quality water, but also essential for maintaining the integrity of the distribution infrastructure (Dion-Fortier et al., 2009).

Water quality in the distribution network is dependent on many factors (Rodriguez et al., 2003). The quality of the treated water is among the most important factor influencing the pattern of the water quality throughout the distribution system. The type of water treatment and source water quality plays in the role. The type of pipe materials is another important factor affecting the water quality in addition to the year of installations and proportion of water leakage. The parts of the distribution system close to the source water are less affected by the water and distribution system interaction. The impact of all these factors on the water quality is often complex and not easy to understand. It is especially true for large water distribution network (Charisiadis et al., 2015).

Several studies involving water quality parameters have been conducted on the water distribution system. Studies were conducted on the variability of disinfection byproduct within the distribution system (Charisiadis et al., 2015; Shanks et al., 2013; Wei et al., 2010). Chlorine decay within the distribution system has also been explored through modelling studies (Cordoba et al., 2014; Nagatani et al., 2006). Some of these studies were limited to one type of pollutant while some studies were restricted to small distribution systems. The use of Geographic Information Systems (GIS) has been used in a limited capacity for water quality assessment in a distribution network, and limited information is found in the literature. Furthermore, large water distribution system is often overlooked in most of these studies.

GIS has been successfully utilised utilised in many studies to understand complex hydrological and environmental processes through the analysis of their spatial and temporal patterns. This includes spatial and temporal analyses of the parameters for some ecological environmental processes (Gebbert and Pebesma, 2014; Xie et al., 2015), distributed hydrologic modelling (Bhatt et al., 2014), and GIS-based regression analysis (Kelsey et al., 2004). A GIS-based Inverse Distance Weighing (IDW) method was used to determine the values of the five quality parameters being considered in this study over the service area (278.2 km2) and along the water distribution network using the values of the parameters collected at all 46 monitoring stations (Chang, 2006; Mesnard, 2013).

The objective of this study was to assess the variations of water quality throughout the water distribution system in Sharjah, UAE. A GIS-based analysis was conducted to assess the variations of water quality. The standard IDW method in ArcGIS 10.2 was used to create an interpolated surface for each parameter while a vector GIS-based version of the method was used to predict the values of the parameters at regular spacing of 50 m along the distribution network (3152.2 km), over the period of study. Temporal variations of water quality were assessed in one particular location in the distribution system network. Several water quality parameters were analysed.

Study the variability of water quality in a large distribution network

STUDY AREA AND NETWORK

Water distribution network within the City of Sharjah was used for this study (Figure 1). City of Sharjah is one of the major cities in the UAE. It is located by the side of the Arabian Gulf and beside the City of Dubai. The distribution network is currently managed by Sharjah Water Electricity Authority (SEWA). SEWA has more than 3000 km of distribution pipe network. Several pumping stations are used to maintain pressure within the distribution network. The pipe networks are mostly made of Asbestos Cement (AC) pipes. In addition Polyethylene (PE) and Polyvinyl Chloride (PVC) pipes are also used in the distribution network. SEWA monitors water quality in the distribution network at 46 locations. These locations are distributed uniformly throughout the distribution network (Figure 1). Water quality monitoring data of these locations were used for the years 2012–2014. Several water quality parameters including pH, Electrical Conductivity (EC), chlorine residual and iron were monitored.

The City of Sharjah grew extensively over the last decades in terms of both the areas covered and the populations served. Therefore, majority of the water distribution pipes are relatively new. Water leakage information indicated a very robust distribution network with around 13–15% leakage in the SEWA network. The water supplied to the SEWA network is from seven different treatment plants that supply desalinated water throughout the distribution network. Most of the desalinated water is via Multi-Stage Flash (MSF) distillation and Reverse Osmosis (RO) processes used to treat the seawater. Inland treatment plants use RO processes to treat brackish water. Due to the multiple sources of water in the network it is often difficult to pinpoint areas of concern accurately by investigating the water treatment plants.

Figure 1 Water distribution network in the City of Sharjah, UAE

METHODOLOGIES

Water quality analysis was conducted based on spatial variability and temporal variability. Temporal variability was studied on a single monitoring location, American University of Sharjah (AUS). Monthly average data were used for 34 available months. The notations for months were used chronologically indicating 1 as January 2012, 2 as February 2012 and 34 as October 2014. The dataset were plotted for pH, EC and residual chlorine for analysis.

The spatial variability was studied using GIS. The average water quality parameters in 2012 was used to create 50-m cell-size raster surfaces using the IDW method in ArcGIS 10.2 utilising the measured parameters values at the monitoring locations. The general form of the IDW function used to find interpolated values of the parameters p at a given point in space s based on the known values $p_i=p(s_i)$ *for* i=1,2,..., n and distance-based weights $w_i(s) = 1/[d(s, s_i)]$ is given below:

$$p(s) = \begin{cases} \dfrac{\sum_{i=1}^{n} w_i(s) p_i}{\sum_{i=1}^{n} w_i(s)} \text{ if } d(s, s_i) \neq 0 \text{ for all } i \\ p_i, \text{ if } d(s, s_i) = 0 \text{ for some } i \end{cases}$$

A vector-based version of this method was used ArcGIS to predict the parameters values at every 50-m spacing along the water network using the sampled parameters values collected at the monitoring stations.

RESULTS AND DISCUSSIONS

Temporal variability

Figure 2 illustrates the pH values of water distributed at AUS. All pH values were within the allowable range of 6.5—9.2. There are no visible pattern or major changes in the pH values between the months. There were two months (August 2014 and September 2014) that had relatively higher pH values of 8.2 and 8.1, respectively. Further investigations are being planned to determine the cause of the discrepancies in these two months.

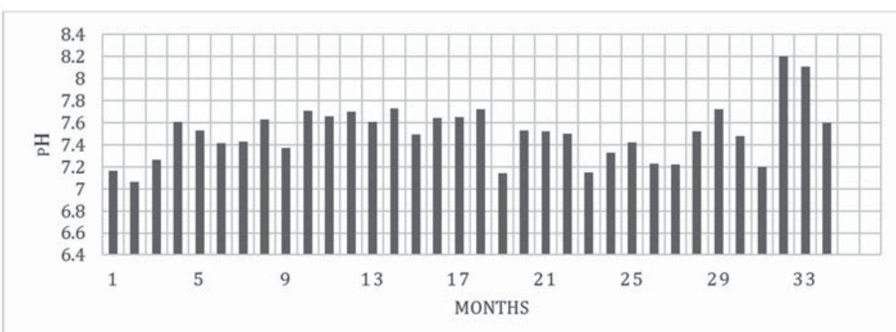

Figure 2 Temporal variations of pH

Figure 3 illustrates the variation in the EC of the distributed water at AUS. There were only two months (September 2012 and July 2013) when the water had higher EC than the maximum allowable limit of 1600 microS/cm. Since EC provides information on the amount of dissolved solids in the water, and which can indirectly relate to the salinity of the water, it can be concluded that the water had low salinity and suitable for drinking.

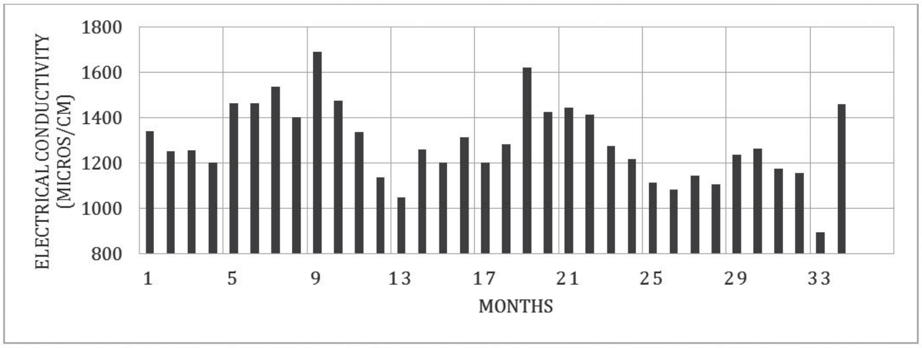

Figure 3 Temporal variations of EC

Figure 4 illustrates the residual chlorine concentration over the three-year period at AUS monitoring location. With the chlorine residual guideline in Sharjah being between 0.2 and 1.0 ppm, the distributed water consistently achieved the chlorine target. There was one exception, in the 30th month (June 2014) when the chlorine concentration was 0.17 ppm. However, it was not possible to determine the cause of the slight reduction. It is worth mentioning that large development projects have been completed and ongoing in recent times in the area that has resulted in an increase in the distribution network size. It is possible that the chlorine injection at the dosing point was insufficient during that month. Recent measurements of residual chlorine concentration in the laboratories and housing complexes at AUS found average values of 0.45 ppm.

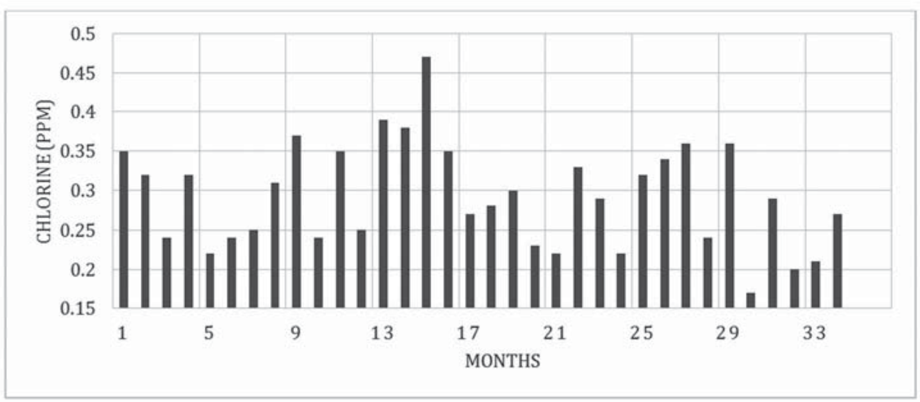

Figure 4 Temporal variations of residual chlorine

Spatial variability

The IDW method has helped in creating the raster-based spatial variability surfaces in the study area as shown in Figures 5–7. Figure 5 shows the vector-based spatial variability maps of pH along the water distribution network in the study area. The spatial distributions of pH over the study area indicated an evident clustering of high values in the part of the study area to the east of Khalid Lagoon.

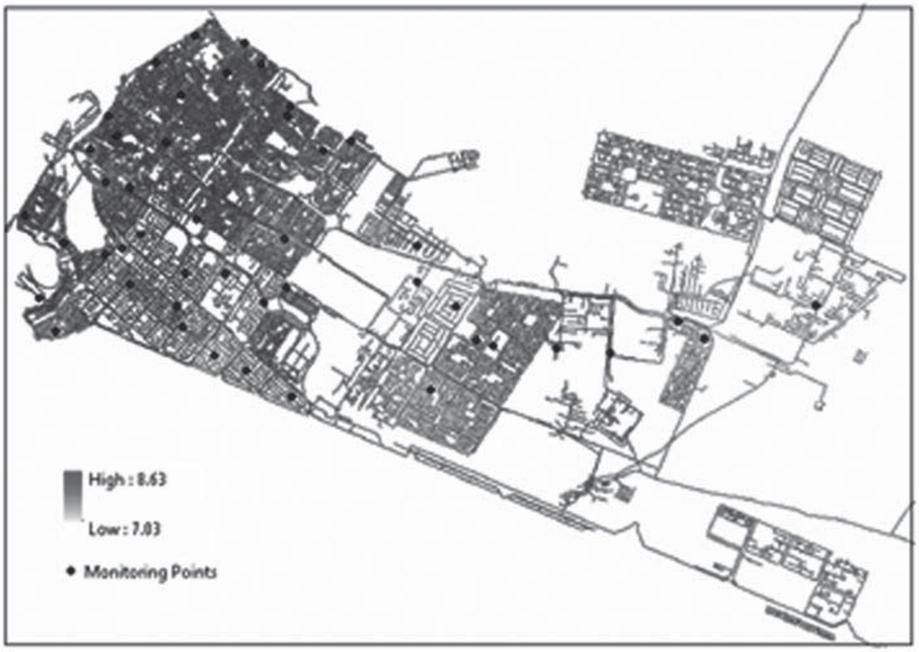

Figure 5 Spatial Variability of pH in 2012 (SD ±0.38)

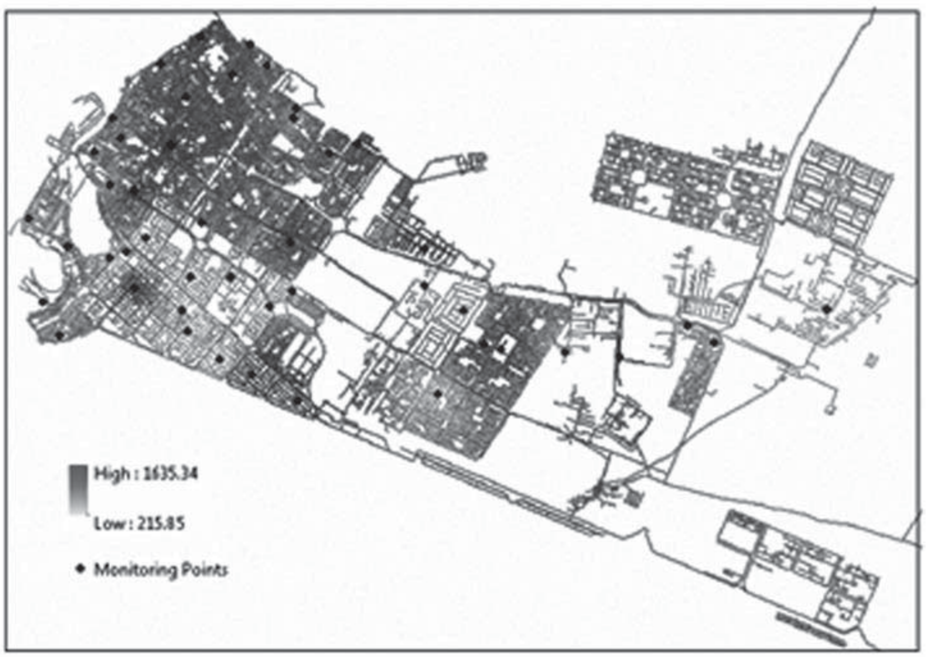

Figure 6 Spatial Variability of EC in 2012 (SD ±509.60)

Figure 6 shows the spatial distributions of EC throughout the SEWA distribution network in 2012. Higher EC values were evident in the older part of the distribution network as opposed to new distribution network having lower conductivity. Old part SEWA distribution network is also closely placed to the Arabian Gulf with high salinity. Also the largest desalination plant supplying the water in the network is close to that area.

Figure 7 shows spatial chlorine distribution in the City of Sharjah in 2012. Chlorine distribution showed clusters of high values at around four of the monitoring stations isolated by lower values across the study area. There were no clear relationship of chlorine residual and the location in the distribution system. It could be due to the reason that multiple sources were supplying water throughout the distribution network.

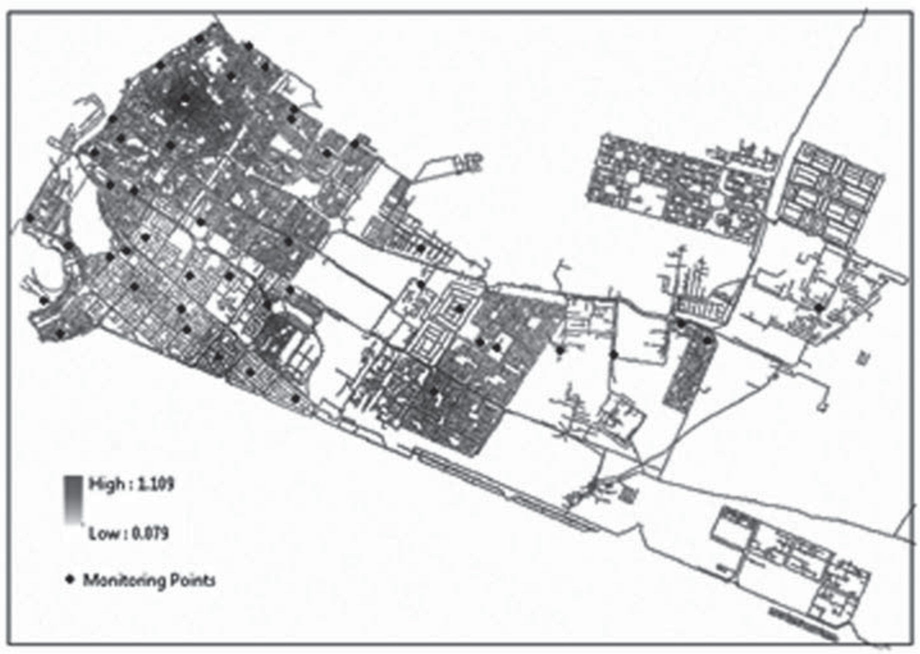

Figure 7 Spatial Variability of Chlorine in 2012 (SD ±0.214)

CONCLUSIONS

The study analysed variations of water quality parameters throughout the distribution network in the City of Sharjah, UAE. It used water quality data from 46 monitoring locations. The study revealed that pH, EC and residual chlorine were consistently maintained throughout three year period for most of the locations. Spatial distribution indicated that water quality close to the Arabian Gulf and old part of the city had slightly different characteristics than the new part of the distribution network.

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REFERENCES

Bhatt, G., Kumar, M. and Duffy, C. (2014) 'A tightly coupled GIS and distributed hydrologic modeling framework', *Environmental Modelling and Software*, Vol. 62, pp.70–84.

Chang, K.T. (2006) *Introduction to Geographic Information Systems*, 3rd edition, New Delhi: Tata McGraw Hill.

Charisiadis, P., Andra, S.S., Makris, K.C., Christophi, C.A., Skarlatos, D., Vamvakousis, V., Kargaki, S. and Stephanou, E.G. (2015) 'Spatial and seasonal variability of tap water disinfection by-products within distribution pipe networks', *Science of the Total Environment*, Vols. 506–507, pp.26–35.

Cordoba, G.A.C., Tuhovcak, L. and Taus, M. (2014) 'Using artificial neural network models to assess water quality in water distribution networks', *Procedia Engineering*, Vol. 70, pp.399–408.

Dion-Fortier, A., Rodriguez, M.J., Serodes, J. and Proulx, F. (2009) 'Impact of water stagnation in residential cold and hot water plumbing on concentrations of trihalomethanes and haloacetic acids', *Water Research*, Vol. 43, No. 12, pp.3057–3066.

Furnass, W.R., Mounce, S.R. and Boxall, J.B. (2013) 'Linking distribution system water quality issues to possible causes via hydraulic pathways', *Environmental Modelling and Software*, Vol. 40, pp.78–87.

Gebbert, S. and Pebesma, E. (2014) 'A temporal GIS for field based environmental modeling', *Environmental Modelling and Software,* Vol. 53, pp.1–12.

Kelsey, H., Porter, D., Scott, G., Neet, M. and White, D. (2004) 'Using geographic information systems and regression analysis to evaluate relationships between land use and fecal coliform bacterial pollution', *Journal of Experimental Marine Biology and Ecology*, Vol. 298, pp.197–209.

Mesnard, L. (2013) 'Pollution models and inverse distance weighting: Some critical remarks', *Computers and Geosciences*, Vol. 52, pp.459–469.

Nagatani, T., Yasuhara, K., Nakamura, T., Fuchigami, T. and Terashima, K. (2006) *Residual Chlorine Decay Simulation in Water Distribution System*, The 7th International Symposium on Water Supply Technology, Yokohama, 22–24 November.

Rodriguez, M.J., Vinette, Y., Serodes, J.B. and Bouchard, C. (2003) 'Trihalomethanes in drinking water of greater Quebec region (Canada): Occurrence, variations and modelling', *Environmental Monitoring and Assessment*, Vol. 89, No. 1, pp.69–93.

Shanks, C.M., Serodes, J. and Rodriguez, M.J. (2013) 'Spatio-temporal variability of non-regulated disinfection by-products within a drinking water distribution network', *Water Research*, Vol. 47, pp.3231–3243.

Wei, J., Ye, B., Wang, W., Yang, L., Tao, J. and Hang, Z. (2010) 'Spatial and temporal evaluations of disinfection by-products in drinking water distribution systems in Beijing, China', *Science of the Total Environment*, Vol. 408, pp.4600–4606.

Xie, H., Yao, G. and Guiying, L. (2015) 'Spatial evaluation of the ecological importance based on GIS for environmental management: A case study in Xingguo county of China', *Ecological Indicators*, Vol. 51, pp.3–12.

BIOGRAPHICAL NOTES

Dr. Md Maruf Mortula is an Associate Professor in the Department of Civil Engineering at the American University of Sharjah (AUS), Sharjah, UAE. He earned his PhD and MASc degrees at the Dalhousie University, Halifax, Canada. He worked at the National Research Council of Canada prior to joining AUS. His research interests are water and wastewater treatment, waste residual management within water utilities, organic waste management and water quality management in the water distribution system and in the coastal areas.

Dr. Kazi Parvez Fattah is an Assistant Professor in the Department of Civil Engineering at the American University of Sharjah (AUS), Sharjah, UAE. He earned his PhD and MASc at The University of British Columbia, Vancouver, Canada. He worked as a consultant in Canada prior to joining AUS. His research interests are in nutrient recovery from wastewater, water sustainability, wastewater reuse and green concrete development.

Dr. Tarig Ali is an Associate Professor of Civil Engineering at the American University of Sharjah (AUS). He earned a PhD in Geoinformation and Geodetic Engineering from the Ohio State University (OSU), USA in 2003. He has taught at East Tennessee State University (ETSU) and at the University of Central Florida before joining AUS. He is the recipient of many international awards. His research interests include GI-Science, coastal mapping, terrain modeling, wide-area GPS networks, and applications of geographic information systems (GIS) and remote sensing in environmental and transportation engineering.