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DRINKING WATER QUALITY MONITORING WITHIN A DISTRIBUTION NETWORK: F-8 AND E-7 SECTORS OF ISLAMABAD

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Abstract

Most pollution of drinking water is caused by inadequacy of distribution system, by inefficient upkeep of the sewage system and by defects in the disinfection processes. This may be the cause of water borne epidemic outbreaks. Concern over the presence of faecal coliform in public drinking water supplies has been expressed in recent years in Pakistan, since it has been regarded as a pathogenic organism, of prime importance in gastroenteritis. It is, therefore, necessary to carry out routine monitoring of the distribution system. The aim of this study was to monitor the quality of water in drinking water supplies at the treatment plant and in the water distribution network of two major sectors, F-8 and E-7, of Islamabad, Pakistan. The drinking water distribution systems were monitored, over the period of one month, to assess the microbial water quality and residual chlorine. The drinking water quality monitoring was performed by collecting samples from the water source and residential taps from each distribution network. The samples were analyzed for physico-chemical indicators (temperature, pH, conductivity, total dissolved solids (TDS), turbidity, total chlorine, free chlorine residual and chloramines) and bacterial indicators (total and faecal coliforms). In the sector F-8, temperature ranged from 19.6°C to 22.6°C, TDS varied between 156.0 mg/L and 268.0 mg/L, turbidity ranged from 2.70 to 8.15 NTU, pH varied from 6.96 to 7.48, conductivity ranged between 325 and 548 µS/cm, total chlorine observed varied between 0.14 mg/L and 0.21 mg/L, total coliforms ranged from undetectable level to 2.2 most probable number (MPN)/ 100 mL. In sector E-7, temperature ranged from 20.4°C to 21.7°C, TDS varied between 157.4 mg/L and 163.2 mg/L, turbidity ranged from 1.30 to 4.46 NTU, pH varied from 7.26 to 7.65, conductivity ranged between 328 and 339 µS/cm, total chlorine observed varied between 0.40 mg/L and 1.00 mg/L, total coliforms ranged from undetectable level to 16.1 most probable number (MPN)/ 100 mL.

Keywords: drinking water; treatment plant; distribution network

Introduction

Clean drinking water is a precursor for a healthy life and a basic human right. More than a billion people in the developing world lack access to drinking water (IHRO, 2007). South Asia is one of the most rapidly developing regions of the world. Increasing population size and industrial activity has resulted in escalated rates of water scarcity and pollution. Water in South Asia may no longer be thought to represent natural water quality; it shows impact of different types of human activities practically in every part of the sub-continent (Subramanian, 2004). Fourteen to thirty thousand people, mostly young children and the elderly, die everyday from water related diseases globally (IHRO, 2007). While in 2007, 3 billion people from South Asia lacked proper sanitation and access to clean water (GWP, 2007). With a considerable amount of water wasted and a large proportion used for irrigation, only a tiny portion, 3% of Pakistan's sweet water reserves, is used for household purposes and drinking. Therefore, the debate about access to water in Pakistan is dominated by irrigation disputes, mega-projects of dams and canals, and climate change. The focus is on water for agriculture rather than for people (Nils, 2005).

Population growth, rapid urbanization and industrialization, are imposing growing demands and pressure on water-resource, which is already deficient. The future, therefore, is likely to be dominated by increasing pressure on water, both driven by the increasing population and rising urbanization. Scarcity, rising demands and competition for water resources has lead to severe misuse of water resources, while the water quality and the environment worsen.

In the sectors of urban and rural water supply, the pace of development has not kept up with the need, whereby significant proportions of the population remain deprived of the benefit of clean water supply and sanitation facilities, resulting in a large cost to the nation in terms of people's health [h]. Results of various investigations provide evidence that most of the drinking-water supplies in both urban and rural areas of Pakistan are faecally contaminated. The poor bacteriological quality of drinking-water has frequently resulted in high incidence of waterborne diseases (Aziz, 2005). Discharging untreated sewage and chemical wastes directly into rivers, lakes and drains has become a customary practice. Prevalence of waterborne diseases in Pakistan is mainly due to contamination of drinking water with municipal sewage and industrial waste at different points of the water distribution network, lack of water disinfection practices and water quality monitoring at treatment plants. Subsequently, Pakistan's water quality ranks as 80th out of 122 nations (UNESCO, 2000) and a majority of the population is exposed to the hazard of drinking unsafe and polluted water (Nils, 2005).

Islamabad, the first planned city of Pakistan, is the federal capital as well. Unfortunately, the drinking water quality in most parts of the city is excruciating. A survey carried out by the NIH (2004) revealed that 75% of water in Islamabad is unsafe for human consumption (WB-CWRAS, 2005). The water supply pipes in the distribution network are worn out. In Pakistan, drinking water supply lines and open sewage drains in the streets are laid side by side. As a result, water is frequently contaminated when pipes erode (WWF Pakistan, 2010). Pipe water in Pakistan is contaminated; either because of leakages with all sorts of bacteria or due to geological conditions and insufficient purification; with abnormally high levels of arsenic and elevated fluoride (Nils, 2005). Due to these factors, the water reaching the end consumer is almost always below the standards set up by the National Drinking Water Policy of Pakistan.

Shortage of qualified manpower and funds has lead to the derisory provision of water and sanitation services. The gap is further enlarged by the lack of unambiguous definition of responsibilities, work plans and targets, and ineffective coordination and communication between federal, provincial and local administrative entities (Haas *et al*., 1983). Taking into consideration the worsening water quality in Pakistan, especially in the rapidly growing urban areas, the study was set upon the monitoring of the water distribution network of Islamabad for chemical, physical and microbiological water quality. Samples were analyzed for physico-chemical indicators (turbidity, total chlorine, free chlorine residual, total dissolved solids (TDS) and conductivity) and bacterial indicators (total and faecal coliform).

Materials and Methods

Twenty four samples were collected from different locations of each sector; F-8 and E-7, during March 2008. From each sector, water samples were collected from the main water source (filtration plants) and consumer ends covering seven residential houses receiving water through city pipelines. The collected samples were analyzed for chlorine residual, (MPN: total coliform and faecal coliform), spread plate count as per Standard Methods (APHA, 2005) (Collins *et al.,* 1985). Physical and chemical parameters such as pH, turbidity, TDS and residual chlorine were analyzed from the samples. Total Coliform and Faecal Coliform test were also performed, as per standard methods (APHA, 2005) (Collins *et al.,* 1985) (US-EPA, 1978), to check the microbiological quality of the water.

Results and discussion

Water quality characteristics

Various physical and chemical parameters were analyzed to evaluate water quality of the samples collected.

Temperature

Water temperature is an important parameter because it is a critical factor in determining the growth of the microorganisms (Ramteke *et al*., 1992). Bacterial growth rates, decay of disinfection residual, corrosion rates and even distribution hydraulics are all affected by water temperature (Kelin *et al*., 2005). Temperature also affects the dissolved oxygen (DO) level in a water body. DO is critical for the survival of aquatic organisms for aerobic respiration. Temperature of the water samples collected was recorded at the time of sampling. The temperatures of water samples from the sector F-8 ranged from 19.6°C (at *Station # F8-8*) to 22.6°C (at *Station # F8-3*), as mentioned in Table 1. Water temperature of samples from sector

E-7 ranged from 20.4°C (at *Station # E7-4*) to 21.7°C (at *Station # E7-2*), as per Table 2. The temperatures of the water samples tested were well above the 12°C limit of the WHO. Figure 1 shows temperature obtained at different sampling points of sectors F-8 and E-7.

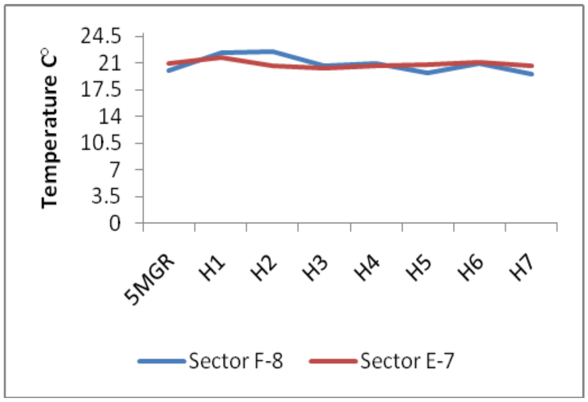

Figure 1: Comparison of average values of Temperature at different sampling stations of sectors F-8 and E-7.

pH

The pH value measured for the F-8 water samples varies from 6.96 to 7.48 (at *Station # F8-2* and *F8-5*), respectively. On the other hand pH measured for the E-7 water samples varies from 7.26 to 7.65 (at *Station # E7-1* and *E7-6* respectively), as shown in Figure 2. All the values are well within the desirable pH range 6.5–8.5 set by the WHO (NSDWQ, 2008). Figure 2 shows pH obtained at different sampling points of sectors F-8 and E-7.

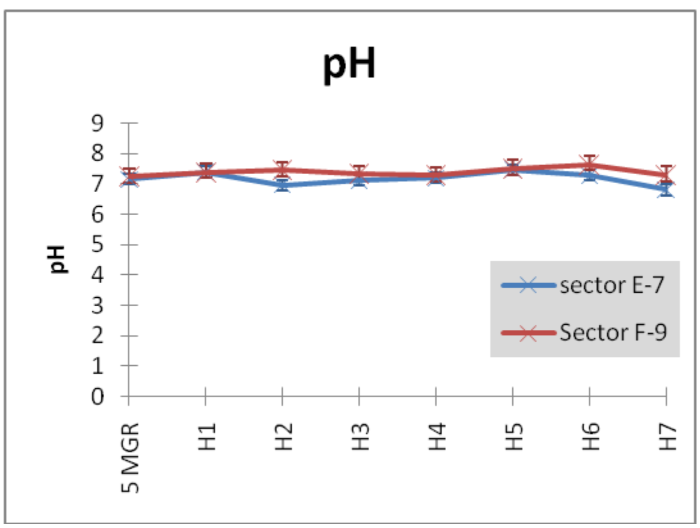

Figure 2: Comparison of average values of pH at different sampling stations of sectors F-8 and E-7.

Conductivity

The value of conductivity varied from 325 µS/cm (at *Station # F8-6)* to 548 µS/cm (at *Station # F8-2)* of the sector F-8, as evident from Table 1. In the E-7, it varies from 328 to 339 µS/cm at *Station # E7-7* and *E7-2* respectively, as given in Table-2. There is a relationship between TDS and conductivity. As the concentration of dissolved salts (usually salts of sodium, calcium and magnesium, bicarbonate, chloride, and sulphate) increases in water, electrical conductivity increases (Kelin *et al.*, 2005). The electrical conductivity is higher for water that has more dissolved ionic species.

TDS

The TDS concentration is considered a secondary drinking water standard, since it is not a health hazard. The presence of high levels of TDS in water may be objectionable to consumers owing to the resulting taste and to excessive scaling in water pipes, heaters, boilers, and household appliances. However, it may also indicate elevated levels of ions that do pose a health concern, such as aluminium, arsenic, copper, lead, nitrate, and others. Water with extremely low concentrations of TDS may also be unacceptable to consumers because of its flat, insipid taste; it is also often corrosive to water-supply systems. The TDS values of the samples from sector F-8, as evidence from Figure 3, ranged from 156.0 mg/L (at *Station # F8-7*) to 268.0 mg/L (at *Station # F8*-3). Whereas TDS values of the E-7 samples ranged from 157.4 to 163.2 mg/L at *Station # E7-5* and *E7-2* as evident from Table 2. Figure 3 shows concentration of Total Dissolved Solids obtained at different sampling points of sectors F-8 and E-7. Water containing TDS concentrations below 1000 mg/litre is usually acceptable to consumers, although acceptability may vary according to circumstances (WHO, 2003). The United States Environmental Protection Agency recommends treatment when TDS concentrations exceed 500 mg/L or 500 parts per million (ppm) (US-EPA, 1978).

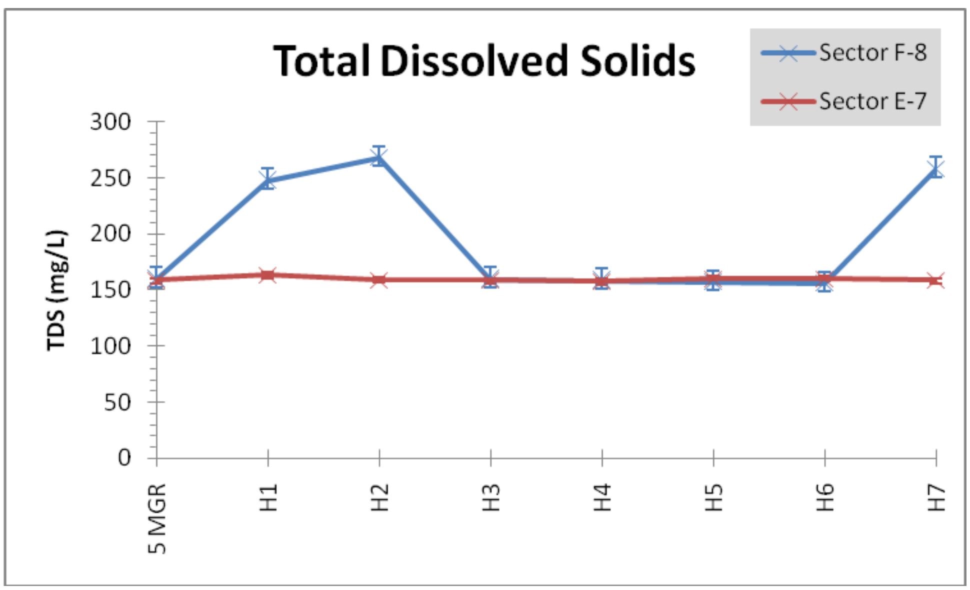

Figure 3: Comparison of average values of Total Dissolved Solids at different sampling stations of sectors F-8 and E-7.

Turbidity

Deterioration in drinking water quality in distribution networks is probably due to an increase in microbial numbers, an elevated concentration of iron or increased turbidity, all of which affect taste, odour, and colour in the drinking water. Turbidity can provide shelter for opportunistic microorganisms and pathogens. Hence, waters with high turbidity, from organic sources, also give rise to a substantial chlorine demand for disinfection purposes. This could result in reductions in the free chlorine residual in distribution systems as protection against possible recontamination. Therefore, increased pre-chlorination dosage requirements are strongly correlated with increases in turbidity. Increase in turbidity resulted in increase of coliform count. Haas *et al.* (1983) noted that increased values of pH, temperature, and turbidity were associated with increased concentrations of microorganisms. These findings are also in line with the study conducted by Parent *et al.* (1996) who studied the control of coliform growth in drinking water distribution systems.

In sector F-8, turbidity values were within the highest desirable level values of WHO, i.e., 5 NTU (NSDWQ, 2008), and ranged from 1.30 (at *Station # F8-2*) to 4.46 NTU (at *Station # F8-5*), as per Table 1. In sector F-7, the turbidity value ranged from the lowest value of 2.70 NTU (at *Station # E7-7*) to the highest value of 8.15 NTU (at *Station # E7-8*), as reported in Table 2. Figure 4 shows the level of turbidity found at different sampling points of sectors F-8 and E-7.Similar results were also reported earlier in a study conducted by the National Water Quality Program, PCRWR (2005), which revealed the range of turbidity from 1.10 to 6.40 NTU (PCRWR, 2005).

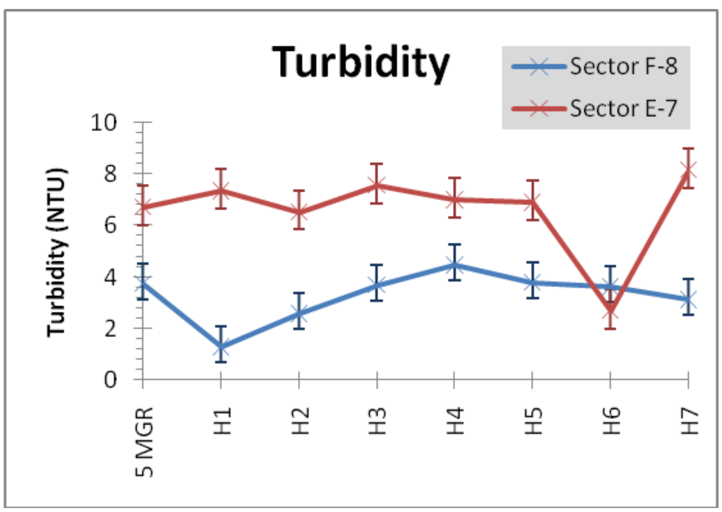

Figure 4: Comparison of average values of Turbidity at different sampling stations of sectors F-8 and E-7.

Chlorine residual

In sector F-8, the value of total chlorine observed varied from the lowest value of 0.14 mg/L (at *Station # F8-2*) to the highest value of 0.21 mg/L (at two stations *Station # F8*-1 and F8-7) as mentioned in Table 1. In sector E-7, the value of total chlorine varied from 0.40 to 1.00 mg/L at *Station # E7-2* and *Station # E7-6* respectively, as evident from Table 2. Free chlorine is the most effective residual disinfectant and may serve as a marker or flag in the distribution network (Olivieri *et al.*, 1986).

The largest value of monochloramines, in sector F-8, was recorded as 0.12 ppm (at *Station # F8*-1), the lowest value was 0.06 ppm at three stations, (*Station # F8-2*, *F8-4* and *F8-7*), as per Table 1. Whereas, in sector E-7, as reported in Table 2, the highest value is 0.25 ppm at two stations (*Station # E7-1* and *E7-6*) and the lowest value is 0.12 ppm (at *Station # E7-7*). The largest value of dichloramines, in sector F-8, was recorded as 0.07 ppm (at *Station # F8-5*), the lowest value was 0.03 ppm (at *Station # F8-2*), as per Table 1. Whereas, in sector E-7, the highest value is 0.22 ppm (at *Station # E7-1*) and the lowest value is 0.05 ppm (at *Station # E7-6*), as mentioned in Table 2. Figure 5 shows concentration of free chlorine obtained at different sampling points of sectors F-8 and E-7. Developing countries, like Pakistan, usually have an inadequate water distribution system; due to which the probability of recontamination is very high in both urban and rural areas. The existence of a disinfectant residual is especially important in such regions (Aziz, 2005). Greater concentration of residual chlorine means there is lesser microbial contamination. Hence, chlorine residuals of drinking water are incredible indicators of the microbial quality of water in distribution networks (Lienyao *et al.*, 2004). The presence of any disinfectant residual reduces the microorganism level and frequency of occurrence at the consumer's tap (Olivieri *et al.*, 1986). Residual chlorine concentrations decline rapidly due to repeated contamination in the distribution system. Since re-chlorination is not practiced, it is difficult to neutralize secondary microbiological contamination of drinking water in the distribution network.

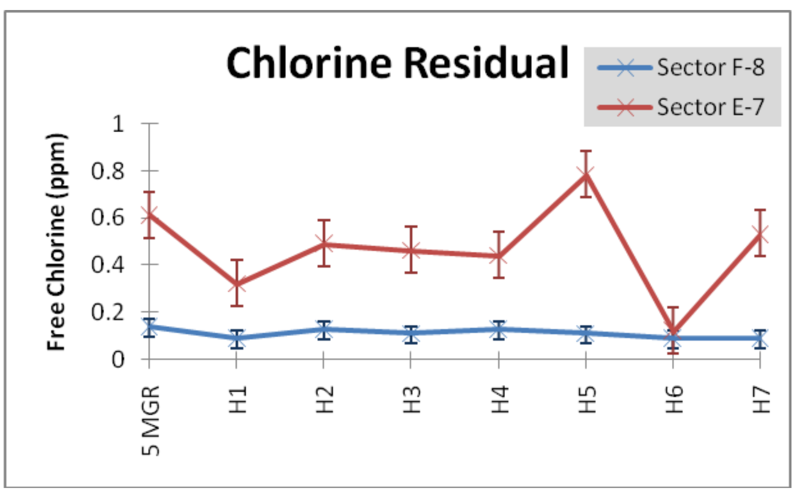

Figure 5: Comparison of average values of free chlorine at different sampling stations of sectors F-8 and E-7.

Microbiological Analysis

The function of SPC bacteria in potable water is of high importance. SPC count is more appropriate for examine microorganisms in potable water than the coliform index (Geldreich *et al.*, 1972) (Muller, 1977). In SPC technique nutrient agar was used as a growth medium and the results were found in CFU/mL. The total viable count obtained was higher in the sector F-8 as compared to the sector E-7. The viable count obtained was as low as 43 CFU/mL (at *Station # F8-3*) to the highest value of 90 CFU/mL (at *Station # F8-6*) in the sector F-8, as per Table 1. Whereas, in the sector E-7, viable count was below countable range of 30 CFU/ml at all the stations except at station # E7-6 i.e. 185 CFU/ml which might be due to poor hygienic condition of water storage tank of consumer House # 5. The water samples collected from the sector E-7 revealed higher counts indicating greater contamination even though the concentration of chlorine was higher in the drinking water. As the chlorine concentration decreases, microbial count increases. Cardenas *et al.* (1993) reported that people in Colombia drinking un-chlorinated water were at increased risk of contracting cholera and diarrhoea with prevalence odds ratios at 5.7 and 3.3, respectively (Cardinas *et al.,* 1993).

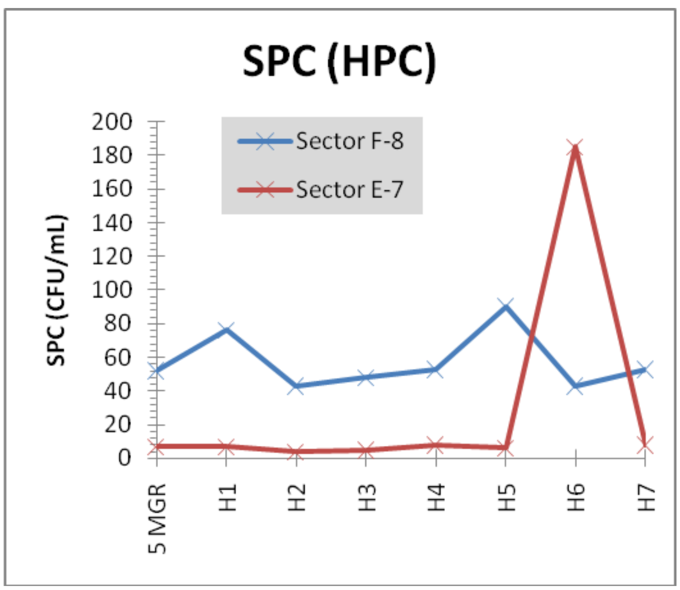

Figure 6: Comparison of average values of SPC counts at different sampling stations of sectors F-8 and E-7.

Most Probable Number

The presence of coliform organisms indicates the biological contamination of drinking water (Le Chevallier *et al.*, 1991). It is not necessary to analyse drinking water for all pathogens. *Escherichia coli* are found in all mammal faeces but it does not multiply significantly in the environment. Hence, it is the best biological drinking water indictor for public health importance (Edberg *et al.*, 2000). To determine the presence of total coliform and faecal coliform in drinking water samples, the MPN test was conducted. The samples were run in triplicate. Water samples from eight different water stations of Sectors F-8 and E-7 were inoculated into LTB tubes. It is a presumptive test for coliform. Evaluation of data obtained revealed that samples collected from the Sector F-8 station were more contaminated with faecal coliform than those obtained from sampling points of the E-7 sections. As evident from Table 1, in sector F-8, the value of MPN/ 100 mL for total coliform was 2.2 and probability ranged from 0 to 3 at all sampling stations except for Station # F8-2 and Station # F8-3 where MPN/100 mL was 2.2 and probability ranged from 0.26 to 8.1 (sector F-8). In the sector E-7, the value of MPN/100 mL for total coliform was found be less than 1.1 and probability ranged from 0 to 3.0 for all Stations except for Station E7-6 where it was 16.1 and the probability ranged from 5.9-36.8. Figure 6 shows SPC of bacteria found at different sampling points of sectors F-8 and E-7. In most developing nations, chlorine residuals are the only final barrier which does not allow microbial degradation of the water quality. The common regulation that demands a "detectable" disinfectant residual may not provide effective consumer protection against microbial contamination. A chloramines residual, instead of free chlorine, may significantly weaken this final barrier against pathogen intrusions (Propato *et al.*, 2004). In a study, it was observed that, as the distance increases from the water reservoir, residual chlorine concentration was significantly reduced at the consumer end causing microbial contaminants to recover to very high levels. Three typical water treatment plants in a northern city (City T) of China and their corresponding distribution systems were investigated. The HPC in distribution systems increased significantly with the decrease of residual chlorine (Lu *et al.*, 2005). Furthermore, in Mexico City, bacteriological contamination increased by 26% from the point of treatment to the consumer's tap (Gaytan *et al.*, 1997).

Drinking water samples of the sector E-7 were less contaminated compared to sector F-8. The results for sector F-8 show lower levels of residual chlorine resulting in high faecal coliform counts at station F8-2 and F8-3 and high levels of SPC counts at all stations. However, the results of sector E-7 show a higher level of residual chlorine at all sampling stations with no contamination of pathogenic microorganisms except at E-7-6 which might be due to poor hygienic condition of over head reservoir or due to mixing of sewage water also resulting in higher SPC. These results are not in confirmation to the WHO bacteriological water quality standards of treated water entering the distribution system, which recommends 0/100 mL for E. coli and total coliform bacteria (WHO, 2003); hence, water is unfit for human consumption. Water quality decay in the distribution network can be caused by properties of pipeline materials, hydraulic conditions, biofilm thickness, excessive network leakages, corrosion of parts, and intermittent service (Lou *et al.*, 2007) (Lee *et al.*, 2005). Current monitoring systems are only for random testing and cannot record pollution level. Chlorination is an appropriate tool to limit coliforms much more easily than the total heterotrophic bacterial biomass. However, in all cases, biofilm-associated bacteria are more difficult to kill than suspended bacteria because of chlorine consumption by the pipe material and because of a diffusion-limited reaction between chlorine and the biofilm (Hashmi *et al.*, 2009). Hence, the water distribution systems were not capable of maintaining high water quality from the water treatment facilities to the end-user.

Conclusions

This study was aimed at assessing the quality of drinking water of Islamabad, to relate the chlorine dosage with microbial contamination, due to the deteriorating water quality. It is anticipated that the monitoring results would lead to remedial measures for improving the current drinking water quality situation in the city. From the analysis of overall water quality, it can be concluded that:

- The samples were collected from eight different sampling points from the water distribution network of two sectors, sector F-8 and sector E-7.
- Total residual chlorine varied largely among different sampling points ranging from lowest value of 0.09 mg/l at sector F-8 to the highest value of 0.78 mg/l at sector E-7.
- At all the stations, of sector F-8 and E-7, the MPN was found less than 1.1 except at *Station # F8-2* and *F8-3*, where the lowest MPN of 2.2, and *Station # E7-6*, where the count of 16.1 was observed.
- Apart from the three stations mentioned above, the results for the faecal coliform test were highly satisfactory as the number of coliforms were below the detectable limit. *Station # E7-6* was found to be the most contaminated due to cross connection of drinking water with domestic wastewater.
- Physiochemical water quality parameters such as pH, temperature, electrical conductivity, total dissolved solids were found within the permissible limits of WHO standards.
- Microbial count was found to be inversely proportional with chlorine residual whereas a direct relationship was observed with turbidity. As the chlorine concentration increased, microbial counts decreased while increase in turbidity resulted in increase in microbial contamination.
- Based upon the results of this study it is recommended that regular monitoring of residual chlorine concentration and total coliforms in the water distribution system should be carried out to ensure that the chlorine residual of 0.2–0.5 mg/l is available at the consumer end.
- The civic agencies, like WASA, CDA and RDA, should take immediate action in this regard. The government, NGO's and civic agencies have to work together to provide clean drinking water, that meets the standards set by NEQS, to the people.

Acknowledgements

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References

- APHA. (2005). *Standard methods for the examination of water and wastewater*. Washington: American Public Health Association.
- Aziz, J. A. (2005). Management of source and drinking-water quality in Pakistan. *Eastern Mediterranean Health Journal*. 11(September 2005):5-6. Retrieved from: http://www.emro.who.int/publications/emhj/1105_6/Artical26.htm
- Cardenas, V., Saad, C., Varona, M. and Linero, M. (1993). Waterborne cholera in Riohacha, Colombia, 1992. *Bulletin of the Pan American Health Organization*. 27(4):313-330.
- Collins, C.H. and Lyne, P.M. (1985). Microbiological methods. *Butterworth & Co Publishers Ltd, London*.
- Edberg, S. C., Rice, E. W., Karlin, R. J. and Allen, M. J. (2000). *Escherichia coli*: the best biological drinking water indicator for public health protection. Department of Laboratory Medicine, Yale University School of Medicine, New Haven, CT, USA. *Symposium Series Society for Applied Microbiology*. (29):106S - 116S.
- Egorov, A., Ford, T., Tereschenko, A., Drizhd, N., Segedevich, I. and Fourman, V. (2002). Deterioration of drinking water quality in the distribution system and gastrointestinal morbidity in a Russian city. *International Journal of Environmental Health Research*. 12(3):221-233. doi:10.1080/09603/202/000000989.
- Farooq, S., Hashmi, I., Qazi, I. A., Qaiser, S. and Rasheed, S. (2008). Monitoring of coliforms and chlorine residual in water distribution network of Rawalpindi, Pakistan. *Environmental Monitoring and Assessment*. 140(1-3):399-347.
- (Gaytan *et al*., 1997) Gaytan, M., Castro, T., Bonilla, P., Lugo, A. and Vilaclara, G. (1997). Preliminary study of selected drinking water samples in Mexico City. *Revista Internacional de Contaminacion Ambiental*. 13(2):73-78.
- Geldreich, E. E., Nash, H. D., Reasoner, D. J., and Taylor, R. H. (1972). The necessity of controlling bacterial populations in potable waters; community water supply. *Journal of the American Water Works Association*. 64:596-602.
- GWP, Global Water Partnership-South Asia. (2007). Retrieved from: http://www.gwpforum.org
- Haas, C. N., Meyer, M. A. and Paller, M. S. (1983). Microbial alterations in water distribution systems and their relationship to physical–chemical characteristics. *Journal of the American Water Works Association*.75:475.
- Hashmi, I., Farooq, S. and Qaiser, S. (2009). Incidence of fecal contamination within a public drinking water supply in Ratta Amral, Rawalpindi. Desalination and water treatment. 11(2009):1-8.

- International Human Rights Observer (IHRO). (2007). *Coping with Water Scarcity*.

  http://ihro.org.pk/downloads/WATERFORLIFE.pdf

- Johnson, P., Graham, N.J.D. and Wilson, M. (1997). Predictive Chlorine Dosing: A New Paradigm. *Water and Environment Journal*. 11(6):413-422.
- Kelin, H., Yuang, H.F., Hong, L. and Robert, W.E. (2005). Spatial variability of shallow ground water level, electrical conductivity and nitrate concentration and risk assessment of nitrate contamination in North China plain. *Environment International*. 31:896-903.
- Kitazawa, H. (2006). Keeping residual chlorine and decreasing unpleasant odor caused by disinfection of tap water. *Water Supply*. 6(2):193-199.
- Le Chevallier, M. W., Norton, W. D. and Lee, R. G. (1991). Giardia and Cryptosporidium spp. in filtered drinking water supplies. *Applied and Environmental Microbiology*. 57(9):2617-2621.
- Lee, E. J. and Schwab, K. J. (2005). Deficiencies in drinking water distribution systems in developing countries. *Journal of Water and Health*. 3(2):109-127.
- NSDWQ, National Standards for Drinking Water Quality. (2008). Pakistan Environment Protection Agency. http://www.environment.gov.pk/act-rules/DWQStd-MAY2007.pdf
- Lienyao, L., Chungsying, L., & Shyang-Lai, K. (2004). Spatial diversity of chlorine residual in a drinking water distribution system. *Journal of Environmental Engineering*. 130:1263-1268.
- Lou, J. C. and Han, J. Y. (2007). Assessing water quality of drinking water distribution system in the South Taiwan. *Environmental Monitoring and Assessment*. 134(1–3):343-354.
- Lu, W. and Zhang, X. J. (2005). Factors affecting bacterial growth in drinking water distribution system. *Biomed Environ Sci. 2005 Apr*. 18(2):137-40. Department of Environmental Science and Engineering, Tsinghua University, Beijing.
- Muller, G. (1977). Bacterial indicators and standards for water quality in the Federal Republic of Germany. *In A. W. Hoadley & B. J. Dutka (Eds.), Bacterial indicators/hazards associated with water*. 159-167. Philadelphia: American Society for Testing and Materials.
- Nils Rosemann. (2005). *Drinking water crisis in Pakistan and the issue of bottled water – The case of Nestlé's 'Pure Life'*. http://www.alliancesud.ch/en/policy/water/downloads/nestle-pakistan.pdf
- Olivieri, V. P., Snead, M. C., Kruse, C. W. and Kawata, K. (1986). Stability and effectiveness of chlorine disinfectants in water distribution systems. *Environmental Health Perspectives*. 69:15-29.

- PCRWR. Pakistan Council of Research and Water Resources. (2005). *National Water Quality Monitoring Programme, Report 2004, Islamabad*.
- Propato, M. and Uber, J. G. (2004). Vulnerability of water distribution systems to pathogen intrusion: how effective is a disinfectant residual? Department of Civil and Environmental Engineering, University of Cincinnati, Cincinnati, Ohio 45221, USA. *Environmental Science & Technology*. 38(13):3713-22.
- Ramteke, P. W., Bhattacharjee, J. W., Pathak, S. P., & Kaira, N. (1992). Evaluation of coliforms as indicators of water quality in India. *Journal of Applied Bacteriology*. 72(4):352-356.
- Subramanian, V. (2004). Water Quality in South Asia. *Asian Journal of Water Environment and Pollution*. 1(1-2(2004)):41-54.

  http://iospress.metapress.com/content/j765b91l5wuwgjxg/
- UNESCO. (2000). *Water quality indicator values in selected countries*.
- UNSP, The United Nations System in Pakistan. *Water—A Vital Source of Life, Islamabad*. (2003). 63.
- US-EPA. (1978). Methods for the chemical analysis of water and wastes. US-EPA-625/6-74-003. Washington, DC:Office of Technology Transfer.
- WB-CWRAS, The World Bank. (2005). Pakistan country water resources assistance strategy water economy: Running dry. Washington, DC: WB-CWRAS.
- World Health Organization (WHO). (2003). *Acceptability aspects. In Guidelines for Drinking Water Quality ed*. Chapter 10. World Health Organization. Geneva.
- WWF, Pakistan. (2010). *Water Pollution Factsheet*. Retrieved from: http://www.wwfpak.org/factsheets_wps.php

Table 1: Mean value of Microbial and Chemical Analysis of Water Samples Collected from

Sector F-8

Water Parameters	Station Numbers							
	F8-1	**F8-2**	**F8-3**	**F8-4**	**F8-5**	**F8-6**	**F8-7**	**F8-8**
Station Name	**5 MGR**	**H1**	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**
Temp (°C)	19.2-20.2 20	21.9-23 22.4	21.4-23.5 22.6	20.3-21.2 20.6	20.1-21.5 21	19.3-20.3 19.7	19.8-21 21	18-20.8 19.6
PH	6.7-7.6 7.15	7.26-7.49 7.4	6.94-6.99 6.96	6.96-7.30 7.12	7.06-7.29 7.2	7.25-7.68 7.48	7.17-7.38 7.28	6.69-7.04 6.81
TDS (mg/l)	155-167.8 160	234-270 248	242-309 268	157-164 159.6	156.4-162.4 158.4	156-158.1 157.1	154.8-156.5 156	252-261 258
Conductivity (µS/cm)	323-335 328	482-538 505	486-635 548	326-332 329	325-328 326	325-327 326	324-326 325	518-538 528
Turbidity (NTU)	2.97-4.21 3.74	0.88-1.61 1.3	1.73-3.63 2.58	3.46-3.91 3.69	3.73-5.68 4.46	3.62-3.89 3.78	3.57-3.7 3.62	1.46-5.98 3.14
Total Chlorine (ppm)	0.1-0.35 0.21	0.1-0.18 0.14	0.12-0.23 0.17	0.13-0.24 0.17	0.13-0.25 0.2	0.13-0.25 0.18	0.13-0.25 0.21	0.08-0.27 0.15
Free chlorine (ppm)	0.08-0.22 0.14	0.05-0.12 0.09	0.06-0.12 0.13	0.08-0.14 0.11	0.08-0.19 0.13	0.07-0.14 0.11	0.07-0.11 0.09	0.06-0.11 0.09
Monochloramine (ppm)	0.07-0.18 0.12	0.04-0.07 0.06	0.04-0.1 0.07	0.06-0.07 0.06	0.06-0.18 0.1	0.06-0.08 0.07	0.06-0.07 0.06	0.05-0.09 0.07
Dichloramines (ppm)	0.04-0.05 0.05	0.02-0.04 0.03	0.05-0.06 0.06	0.04-0.08 0.06	0.05-0.11 0.07	0.04-0.06 0.05	0.05-0.06 0.05	0.04-0.06 0.05
Total Coliform (MPN index/ 100ml)	<1.1	2.2	2.2	<1.1	<1.1	<1.1	<1.1	<1.1
Faecal Coliform	<1.1	2.2	2.2	<1.1	<1.1	<1.1	<1.1	<1.1
Range 95% Probability	0-3.0	0.26-8.1	0.26-8.1	0-3.0	0-3.0	0-3.0	0-3.0	0-3.0
SPC (HPC) (CFU /ml)	52	76	43	48	53	90	43	53

NTU = Nephlometric turbidity units, **CFU** = Colony Forming Units, **MGR =** Million Gallon Reservoir, **H (1, 2, 3, 4, 5, 6, 7)** = Consumer Houses

Note: Top reading in each cell refers to range and bottom reading to the mean value

* Based on mean of three replicates (Dated: 25/03/08, 27/03/08 and 31/03/08).

Table 2: Mean value of Microbial and Chemical Analysis of Water Samples Collected from

Sector E-7

Water Parameters	Station Numbers							
	E7-1	**E7-2**	**E7-3**	**E7-4**	**E7-5**	**E7-6**	**E7-7**	**E7-8**
Station Name	**5 MGR**	**H1**	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**
Temp (°C)	18.3-23.4 20.9	19.7-25.5 21.7	17.7-25 20.6	17.3-24.8 20.4	17.9-24.8 20.7	17.9-23.8 20.8	17.4-23.8 21.2	17.9-23.3 20.6
pH	6.96-7.53 7.26	7.19-7.69 7.4	7.3-7.69 7.47	7.14-7.65 7.34	7.14-7.61 7.3	7.30-7.73 7.52	7.46-7.83 7.65	7.10-7.63 7.31
TDS (mg/l)	156.3-159.5 158.3	161-167 163.2	156-160.7 158.7	155.6-160.5 108.3	154.9-160 157.4	156.6-163.7 160	158.3-160.7 160	155.4-159.9 158.1
Conductivity(µS/cm)	331-325 329	334-347 339	325-334 330	322-334.4 328.8	323-332 328	321-340 331	330-333 332	321-331 328
Turbidity (NTU)	6.16-7.54 6.75	6.47-8.33 7.35	6.10-7.30 6.53	6.66-8.41 7.57	6.19-7.63 7	6.40-7.90 6.89	1.88-3.80 2.7	7.5-8.75 8.15
Total Chlorine (ppm)	0.7	0.4	0.55	0.52	0.51	1	0.46	0.62
Free chlorine (ppm)	0.47-0.73 0.61	0.22-0.39 0.32	0.31-0.61 0.49	0.41-0.50 0.46	0.4-0.51 0.44	0.65-1.00 0.78	0.09-0.16 0.12	0.45-0.67 0.53
Monochloramine (ppm)	0.18-0.40 0.25	0.15-0.2 0.17	0.14-0.34 0.22	0.16-0.26 0.19	0.17-0.33 0.23	0.18-0.35 0.25	0.09-0.15 0.12	0.15-0.19 0.17
Dichloramines (ppm)	0.10-0.38 0.22	0.05-0.18 0.11	0.09-0.13 0.11	0.06-0.15 0.1	0.07-0.28 0.15	0.06-0.21 0.13	0.04-0.07 0.05	0.13-0.17 0.15
Total Coliform (MPN index/100ml)	<1.1	<1.1	<1.1	<1.1	<1.1	16.1	<1.1	<1.1
Faecal Coliform (MPN index/100ml)	<1.1	<1.1	<1.1	<1.1	<1.1	16.1	<1.1	<1.1
Range 95% Probability	0-3.0	0-3.0	0-3.0	0-3.0	0-3.0	5.9-36.8	0-3.0	0-3.0
SPC (HPC) (CFU /ml)	7	7	4	5	8	6	185	8

NTU = Nephlometric turbidity units, **CFU** = Colony Forming Units, **MGR =** Million Gallon Reservoir, **H (1, 2, 3, 4, 5, 6, 7)** = Consumer Houses

Note: Top reading in each cell refers to range and bottom reading to the mean value

* Based on mean of three replicates (Dated: 25/03/08, 27/03/08 and 31/03/08)