# Analysis of Physico-chemical and Microbial Quality of Urban Piped Water Supply and Associated Health Burden in Two Cities in Bangladesh

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***Abstract:*** It is reported from many developing countries that the supply water arriving to the consumer end points through the distribution networks becomes unsafe for human consumption. There is piped water supply in major cities in Bangladesh; however, physico-chemical and microbiological compliance of the supply water especially at the users' end points is rarely available. This study was designed to assess the quality of supply water at the users' end points and the associated microbial health burden in two cities in Bangladesh. Physico-chemical parameters and bacteriological quality were monitored in rainy and dry seasons in both municipalities. The results revealed that the physico-chemical quality of supply water often exceeds the allowable range set for Bangladesh drinking water quality standard. Both Total Coliforms (TC) and *Escherichia coli* (*E.coli)* were present in a significant number of supply water samples indicating microbial contamination of water during passing through the distribution networks. The estimated disease burdens are much higher than the World Health Organisation (WHO) recommended level of 1.0 μDALY/person.yr and both viral and bacterial pathogens dominate the microbial disease burdens. Control of microbial risks through preventive measures, maintenance and consistent monitoring according to WHO water safety plan (WSP) is recommended to protect the supply water quality and to reduce the microbial health burdens associated with water supply systems in both municipalities.

***Keywords:*** *Supply water quality, μDALY, user's end point, E.coli, Bangladesh.*

## 1. Introduction

Access to a treated, piped water source has proved to be crucial in the improvement of public health and decreased transmission of infectious diseases related to water (Nelson, 2001). The urban dwellers mostly depend on piped water supply for domestic water uses, which is believed to be safe potable water. However, in the recent years there has been a growing concern among the urban people regarding safety and aesthetical qualities (color, taste and odour) of piped water supplies (Geldreich 1996). Water released from the water treatment plant or production tubewell into the distribution system becomes altered during its passage through pipes, reservoirs, storage tanks, standpipes and others. It was reported from developing countries that quality of the water arriving to the consumers end points through the distribution networks is quite unsafe for human consumption (Lee and Schwab, 2005). It is evident that the topic of distribution systems as significant contributors to water-related diseases is slowly gaining recognition globally. Despite the growing interest, there is a limited amount of information regarding this topic especially from least developing countries like Bangladesh.

Use of unreliable water supply of poor quality may cause outbreaks of water borne diseases (like Diarrhea, Dysentery, Cholera, Hepatitis A, Amoebiasis, Gastroenteritis and others) and water based diseases (like Schistosomiasis, Dracumuliasis, Guinea worm and other illness). Waterborne disease contributes a significant proportion of the total disease burden associated with diarrhea and other gastro-intestinal diseases, estimated at 2.2 million deaths and over 72 million disability adjusted life year (DALYs) (Howard and Bartram, 2005). To protect consumers

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from waterborne and water based diseases, water supply authorities should ensure that the supply water is completely free of pathogenic microorganisms as well as harmful chemicals (Pereira et al. 2009). Potable water of poor quality can cause social and economic problems through water related epidemics (Pritchard et al. 2007). Several studies reported poor microbial quality of the supply water at the consumers' end points causing diarrhoeal disease and other gastrointestinal illness (Dany et al. 2000; Basualdo et al. 2000; Agard et al. 2002; LeChevallier at al. 2003; Lee and Schwab 2005; Hunter et al 2005). Few epidemiological studies have also established associations between declining water quality from distribution systems and increased risk of gastrointestinal illness (Semenza et at. 1998; Memrin et al 1999; Egorov et al. 2002). Chaidez et al. (2008) has conducted drinking water microbiological survey together with physico-chemical parameters of two municipalities of the state of Sinaloa, Mexico and found the presence of bacteria in households' tap water. Mulamattathil et al. (2015) has undertaken a study to analyze the physico-chemical and bacteriological quality of drinking water supplied through distribution systems in Mafikeng, the capital of the North West province of South Africa. It was found that the bacteriological quality of the water in the Mafikeng distribution systems was unacceptable due to widespread occurrence of *Pseudomonas* spp. and Heterotrophic Plate Count (HPC).

Adequate supply of safe water is essential for a clean, good hygienic and sanitary urban environment and also to maintain a sustainable urban development. The quantity and quality of urban water supply is closely related as both affect the personal hygienic and health of the people depending on urban water supply. It is one of the prime consideration and major responsibility of the water supply authority to ensure that all residents have convenient and continual access to a clean water supply. Urban population in the developing countries has increased rapidly over the last decades, which has already strained the existing infrastructure of urban water supply and sanitation services to meet the growing demand. In developing countries, the costs of disease and productivity losses linked to inadequate clean water and sanitation are equivalent to 2% of gross domestic demand (Norstrom, 2007). Urban population in major cities in Bangladesh is increasing rapidly, as a result of natural urban growth and migration from rural areas. In 1974, only 8.8% of the total population lived in urban areas and this figure rose to about 25.0% in 2004. Although, the country is currently predominated by rural population; however, it is expected that urban population will be about 40% by 2025, about 60% by 2050 and over two third by 2100 (BBS, 2005). The current urban population is about 38 million and will be reached to about 74 million by 2035. This will add significantly to a large number of people living without access to clean water supply and adequate sanitation in urban areas. Moreover, unplanned urbanization and financial constrains are creating major environmental problems especially in bigger cities and towns, which includes inadequate utility services like water supply and sanitation, pollution of environment from inadequate wastewater, solid and human waste management and drainage facilities. These together with industrial pollution around urban centers are affecting water quality and health surveys showed that over 10% of all morbidity in urban areas is attributable to environmental conditions (World Bank, 2005).

In developing country like Bangladesh, much effort and attention have been paid to increase urban water supply to meet the growing demand rather to improve and maintain the quality of supply water. The information about the physico-chemical and microbiological compliance of the supply water especially at the users' end points is rarely available. This study was conducted with the aim of assessing the supply water quality at the users' end points and the associated health burden in two municipalities in Bangladesh.

## 2. Materials and Methods

### 2.1 Study Sites

This study was conducted in Khulna City Corporation (KCC) and Jessore Municipality (JM), situated at the south-west of Bangladesh as shown in Figure 1. The area of KCC is about 45.65 $km^2$ comprising 31 wards with a population of about 0.9 millions (NRPL, 2004). Out of 31 wards, KCC is now providing pipe water supply in 23 wards. The area of JM is about 25.72 $km^2$ consists of 9 wards, with a total population of 0.2 millions (BBS, 2012) and has water supply in all wards. In both areas, groundwater is extracted by production tubewells, which is delivered into the distribution networks without any treatment except chlorination. The water supply in both areas is intermittent in nature.

### 2.2 Water Sampling and Analysis

To evaluate the water quality of KCC and JM water supply, a comprehensive water sampling from the users' end points before entering the water into the underground storage reservoirs was undertaken in 2010 and 2011. There is water supply in 23 wards in KCC. Two water samples from two preselected households of each ward in rainy season (July-August) and four samples from four preselected households of each ward in dry season (April-May) were collected (total of 138 samples). In JM, water sample was collected from 34 stand posts located around the municipality area both in rainy and dry seasons (total of 68 samples). Water samples for physico-chemical analysis were collected into clean plastic bottles of 2.0L capacity; whereas for microbiological analysis water samples were collected into sterilized plastic bags of 250 mL capacity supplied by HACH. Water samples after collection were transported immediately to the Environmental Engineering laboratory of Khulna University of Engineering & Technology (KUET) for subsequent laboratory analysis. Water samples were tested for physico-chemical and bacteriological quality as shown in Table 1. Analysis for Total Coliforms (TC) and *E.coli* was done on the same day of water sampling in the laboratory according to membrane filtration technique (APHA, 2000). Physico-chemical parameters were tested according to Standard Methods (APHA, 2000) and HACH recommended procedures. The water quality data was used to verify the compliance with both Bangladesh Water Quality Standard (ECR, 1997) and WHO guidelines value (WHO, 2006).

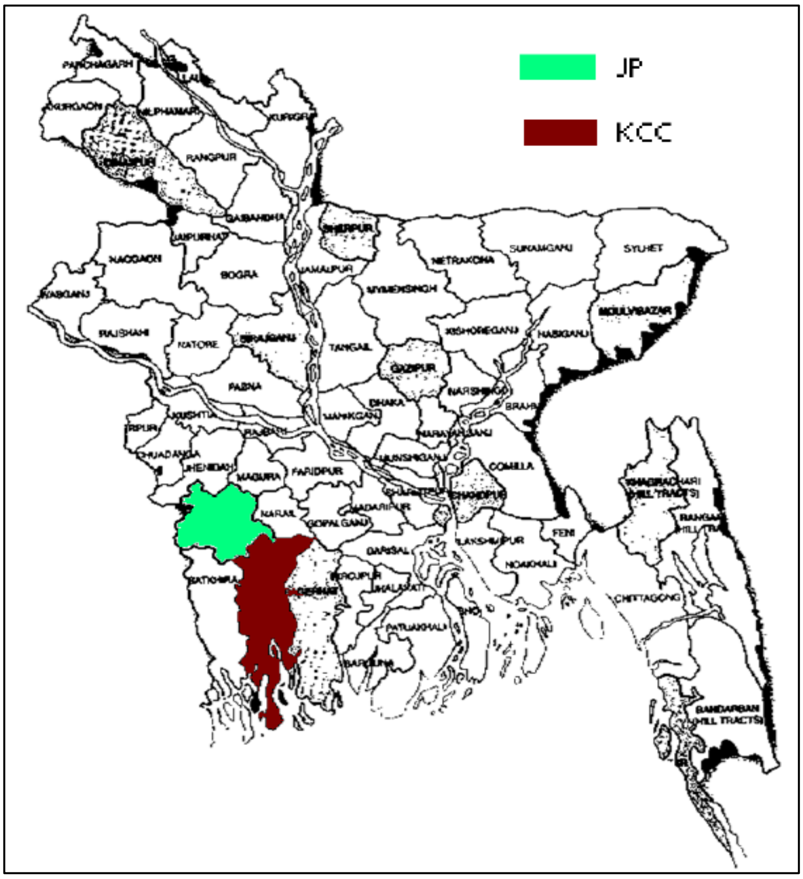


**Figure 1** Map of Bangladesh and the location of the study areas.

**Table 1** Water quality parameters for assessment.

| **Physical Parameters** | **Turbidity, Color** |
|---|---|
| Chemical Parameters | pH, Hardness, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Chloride ($Cl^-$) |
| Bacteriological Parameters | Total Coliforms (TC), *E.coli* |

### 2.3 Health Risk Assessment

A Quantitative Health Risk Assessment (QHRA) model developed by the Arsenic Policy Support Unit (APSU) of Bangladesh (Ahmed et al., 2005; Howard et al., 2006; Howard et al., 2007) was used to quantify the likely disease burdens associated with the water supply. The model estimates microbial disability-adjusted life years (DALYs) for three reference pathogens: rotavirus, cryptosporidium and *E.coli* for viral, protozoal and bacterial disease, respectively, to determine the total disease burden. In this study, the *E.coli* data were used to estimate the likely disease burden in DALYs, a globally applied matrix as recommended by the WHO (2006) to compare different disorders and diseases with different health outcomes. The data obtained were subjected to statistical analysis using Microsoft Excel 2010. The two-tailed test of significance ($p < 0.05$) was used to determine the significance of the result.

## 3. RESULTS AND DISCUSSION

### 3.1 Physico-chemical Parameters

The summary of the measured physico-chemical water quality of two municipalities is shown in Table 2. Results were compared with Bangladesh drinking water quality standard (ECR, 1997) and WHO guideline values (WHO, 2006) to ascertain for compliance with drinking water quality standards. The turbidity and pH of all the water samples were well below the recommended standards; however color of 27% and 77% water samples from JM and KCC, respectively was found to exceed the allowable limit. The color is mainly due to the presence of iron in supply water. It was observed that the values of EC, chloride, hardness and TDS of KCC water supply are much higher than JM water supply and a significant percentage of water samples from KCC exceed the maximum allowable limit. Higher EC, TDS and hardness indicate the presence of excessive inorganic salts in groundwater in Khulna as the city is located closed to the coastal belt of Bangladesh. These may impart noticeable taste or other properties that are deemed objectionable (e.g. discoloring of food, staining of laundry and precipitation of solids in cookware). The analysis indicated that physico-chemical quality of supply water in JM is better than KCC water supply. The pH of supply water should be maintained in between 6.5 to 8.5 to avoid corrosion of metal pipes and also to avoid better (high pH) or sour taste (low pH) of water (DWA, 2006). There is no health consequences attributed to pH of water, except at extreme values which may cause irritation of the mucous membranes (Mulamattathil et al. 2015). As the pH values of water samples in both municipalities were within the allowable range (6.5 - 8.5), it is not likely to cause corrosion of neither the pipe materials nor causing any acidic or alkaline condition of supply water.

### 3.2 Bacteriological Quality

Total coliforms (TCs) are a large collection of different kinds of bacteria while faecal coliforms (FCs) are those that exist in faeces. *E.coli* is a group of FC (USEPA 2013). TC and *E.coli* are indicator organisms and are generally used for assessing of microbiological safety and the potential occurrence of pathogens in water (Okeke et al. 2011). Their presence in drinking water indicates also the presence of disease-causing organisms (pathogens) that are associated with intestinal infections, dysentery, hepatitis, typhoid fever, cholera and other illnesses (Emmanuel et al. 2009). Presence of *E.coli* in water indicates faecal pollution of water from human faeces possibly due to sewage discharge, insufficient treatment or an ineffective distribution system (Pathak and Gopal 2008) and is responsible for bloody and non-bloody diarrhoea, haemorrhagic colitis and haemolytic uremic syndrome (Olsen et al. 2002; Tozzi et al. 2003). Both WHO (2006) and ECR (1997) adopted a stringent standard of 0/100 mL for TC and *E.coli* in drinking water.

**Table 2** Summary of the physico-chemical parameters of supply water in two municipalities.

| Parameters | Unit | Max | | Min | | Average | | BDS | WHO GV | % exceeding BDS value | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | JM | KCC | JM | KCC | JM | KCC | | | JM | KCC |
| Turbidity | NTU | 9.90 | 3.60 | 0.60 | 0.90 | 2.60 | 2.09 | 10 | 5 | 0 | 0 |
| Color | Pt.Co | 147 | 89 | 0 | 0 | 16.5 | 34.5 | 15 | 15 | 27 | 77 |
| pH | - | 8.45 | 8.49 | 6.79 | 7.09 | 7.2 | 7.95 | 6.5-8.5 | - | 0 | 0 |
| EC | μS/cm | 809 | 2611 | 230 | 648 | 443.1 | 1231 | 600-1000 | - | 0 | 70 |
| Chloride | mg/L | 495 | 750 | 16.25 | 160 | 145.9 | 479 | 150-600 | 250 | 0 | 24 |
| Hardness | mg/L as $CaCO_3$ | 789 | 1628 | 109 | 202 | 354.4 | 756 | 200-500 | - | 7 | 73 |
| TDS | mg/L | 403 | 1687 | 120 | 259 | 211.3 | 769 | 1000 | 1000 | 0 | 15 |

Table 3 shows the summary of the microbiological test results obtained from two municipalities. It reveals that TC was found in all water samples collected from KCC in two different seasons and *E.coli* was detected in about 78% samples. In JM, TC and *E.coli* were detected in 76% and 71% samples, respectively. The maximum and minimum counts of TC were found to be 31 No/100 mL and 2 No/100 mL, respectively. The maximum and minimum counts of *E.coli* were 18 No/100 mL and zero respectively, for KCC water supply. There is no significant variation of the occurrence of TC and *E.coli* in supply water in rainy and dry seasons ($p<0.05$). The maximum and minimum counts of TC were 59 and zero per 100 mL samples, whereas the maximum and minimum counts of *E.coli* were 19 and zero per 100 mL samples. A significant variation of the occurrence of TC and *E.coli* in supply water in JM in rainy and dry seasons was observed ($p<0.05$). Analysis of all data showed that overall there is no significant variation of the occurrence of TC and *E.coli* in supply water in both municipalities ($p<0.05$).

**Table 3** Summary of bacteriological parameters of supply water in two municipalities

| Parameters | Unit | Max | | Min | | BDS Standard | WHOGV | % unacceptable according to BDS and WHOGV | |
|---|---|---|---|---|---|---|---|---|---|
| | | JM | KCC | JM | KCC | | | JM | KCC |
| TC | No/100 ml | 59 | 31 | 0 | 2 | 0 | 0 | 76 | 100 |
| *E.coli* | No/100 ml | 19 | 18 | 0 | 0 | 0 | 0 | 71 | 78 |

*Note: Water samples with TC and E. coli > 0 No./100 mL is unacceptable.*

A significant microbial health hazard is associated with drinking water including diarrhea and a range of other diseases, some with significant chronic sequelae (Howard et al. 2006). Analysis of water from the production wells showed that water is completely free from microbial pollution at source. As TC and *E.coli* are detected into a significant numbers of supply water samples, the supply water is subjected to faecal pollution while transporting through the distribution networks in both municipalities. Supply water exhibiting faecal contamination at any point in the distribution networks may potentially contain pathogens, which might cause adverse health effect. Supply water failed to meet the standard set by WHO (2006) and ECR (1997) and failure to comply with bacteriological standards demonstrate that the water is not safe for human consumption. Due to widespread occurrence of TC and *E.coli* in supply water of both municipalities, the water reaching the consumers' end points through the pipe networks is unacceptable for drinking without any in-house water treatment like filtration or chlorination.

### 3.3 Microbial Health Risk

The microbial DALYs were estimated for three reference pathogens like rotavirus, *Cryptosporidium* and *E. coli* O157:H7 for viral, protozoal and bacterial disease, respectively in calculating total disease burden. The estimated median disease burden for both municipalities is shown in Figure 2. It reveals that the estimated disease burden is much higher that the WHO recommended disease burden of 1.0 μDALYs/person.yr (WHO 2004; Howard et al. 2006). Even at the lower estimation (5 percentile), the health burden is also much higher than the WHO recommended level. Although the estimated median health burden at JM is relatively lower than KCC, microbial contamination of the pipe water supply in both municipalities possesses a significant risk of waterborne diseases. The estimation also reveals that viral reference pathogens are the major contributors to the total microbial risk assessment predictions, whereas both bacterial and protozoal burden contributing relatively negligible risk to the total. The importance of viral pathogens from supply water raises important questions that must be paid proper attention. It is likely, however that viral disease burdens from water in developing countries have historically been under estimated as most clinical data was derived for bacterial pathogens.

The study findings reveals that the supply water becomes microbiologically contaminated while transporting through the distribution networks in both municipalities. There may be several causes of water pollution into the piped networks. The water supplies in both municipalities are intermittent in nature, which may cause stagnancy of water and growth of microorganisms. Transient negative pressure and leakage in pipeline may permit the entry of fecal indicators and microbial pathogens present in the soils and water exterior (Chaidez et al. 2008). Bacteria may also enter the distribution network through the failure to maintain a proper disinfection residual, low water pressure in pipeline, intermittent service, corrosion of parts and inadequate sewage disposal (Lee and Schwab 2005). Several other factors like ageing, stressed or poorly maintained distribution systems can cause quality of pipes water to deteriorate below acceptable levels and pose serious health risks (Lee and Schwab, 2005). These flaws in the distribution system often work in combination with each other and can seriously compromise both quantity and quality of water reaching the consumer. The possible causes of contamination, mechanisms and growth of pathogens in the distribution networks need to be further investigated. In both municipalities, it was observed that the water is delivered directly from the production wells into the distribution systems without any treatment even without chlorination. Presence of certain residual chlorine is especially important to prevent the risk of re-contamination into the distribution networks. The WHO recommends maintaining a chlorine residual of 0.2 to 0.5 mg/L into the distribution system under normal operating conditions (WHO 1997). A higher residual concentration than the WHO recommended level must be maintained, where the contamination risk of water in the pipelines is greater.

Thus, both municipalities should adopt the appropriate technological interventions to maintain recommended residual chlorine in order to prevent contamination of the supply water and also to deliver safe water through the pipe networks.

A number of suggestions to improve the operation, maintenance and sustainability of water supply system have been described by World Bank (2001). Some of these recommendations like routine and preventive maintenance such as leak detection and repair, maintaining a minimum pressure in the system and monitoring water quality should be undertaken by the water supply authority. The findings of this study also support the emphasis of the World Health Organization on the Water Safety Plan (WSP) approach (WHO, 2004) in which rigorous water quality risk management plans need to be implemented to protect drinking water quality consistently and thus to reduce health burdens of water borne diseases in developing countries. The topic of distribution systems as significant contributors to water-related diseases is slowly gaining recognition globally (Lee and Schwab, 2005) and very few research and data are available in Bangladesh. More research and monitoring for urban piped water supply in Bangladesh and similar other countries are highly essential.

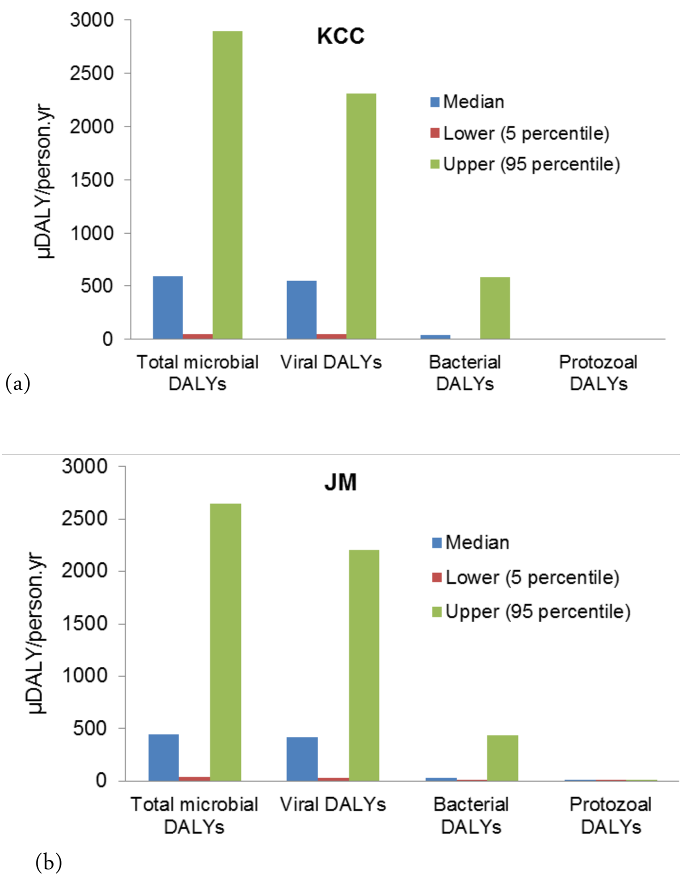


**Figure 2** Estimated median health burden of water supply in two municipalities (a) KCC, (b) JM

Community shows reluctant in using the supply water of poor quality. A survey (Rahman and Murtaza, 2003) in KCC area showed that about 90% of the households of the city use either shallow and deep tubewells water for drinking and peoples are reluctant to use supply water for drinking as it is often found contaminated, filth and bad odor. The supply water is mainly used for cooking, washing and bathing and only 4.20% used supply water for drinking (Rahman and Murtaza, 2003). It seems important to establish a technical surveillance unit and undertake water safety plant (WSP) according to WHO guidelines for consistent monitoring the physio-chemical and microbiological water quality and also to identify the possible contamination pathways and adopting the remedial measures.

## 4. CONCLUSION

The urban piped water supply for drinking and other domestic uses must be of prescribed standards for physio-chemical and microbial quality. This study results revealed that several physico-chemical parameters of the KCC and JM piped water supply at the users' end points exceeded the maximum allowable limits for drinking water. The bacteriological quality of the water in both municipalities is unacceptable as widespread occurrence of TC and *E.coli* was found in the supply water. The estimated disease burdens associated with the water supply in both municipalities are much higher than the WHO recommended level of 1.0 μDALY/person.yr and both viral and bacterial pathogens dominated the microbial disease burdens. Water borne diseases associated with urban water supply constitute a major health burden in the urban centers in Bangladesh. A WSP needs to be undertaken urgently for both KCC and JM water supply in order to protect supply water quality consistently and to ensure safe water supply to reduce the associated health burdens. In both municipalities, groundwater is supplied directly by the production wells into the distribution system without proper chlorination. Proper chlorination and technological interventions are suggested to maintain appropriate residual chlorine in water in order to prevent microbial re-growth and contamination of water in the distribution networks. The QHRA model used in this study can be used for assessing the degree to which technological interventions and the resulting water quality improvement and health risk reduction will be achieved.

The study findings are based on water quality data for a limited period, thus it is recommended to undertake routine monitoring for TC and *E.coli* by both municipalities and evaluate the possible causes of microbial contamination of the water into the distribution network. Water contamination may also be occurred during water storage both into the underground reservoirs and overhead tanks located at the customers' premises. The underground reservoir and overhead tank are the integrated part of water supply in most cities in Bangladesh. Thus, in addition to routine monitoring of the supply water quality, an integrated water quality management approach emphasizing community participation and awareness and a protocol in regular and proper cleaning of the households' reservoirs should be adopted for the safe urban water supply in Bangladesh and other developing countries.

## References


Agard L, Alexander C, Green S, Jackson M, Patel S, Adesiyun A (2002). Microbial quality of water supply to an urban community in Trinidad, *Journal of Food Protection*, 65(8), 1297-1303.

Ahmed MF, Shamsuddin SAJ, Mahmud SG, Rashid H, Deere D, Howard G (2005). Risk Assessment of Arsenic Mitigation Options (RAAMO), APSU, Dhaka, Bangladesh.

APHA (2000). Standard Method for the Testing of Water and Wastewater, American Public Health Association, NY.

Basualdo J, Pezzani B, De Luca M, Cordoba A, Apezteguia M (2000). Screening the municipal water system of La Plata, Argentina, for human intestinal parasites, *International Journal of Hygiene, Environment and Health*, 203(2), 177-182.

BBS (2005). Statistical Year Book of Bangladesh, Bangladesh Bureau of Statistics (www.bbs.gov.bd), Government of Bangladesh.

BBS (2012). Statistical Year Book of Bangladesh, Bangladesh Bureau of Statistics, Government of Bangladesh.

Chaidez C, Sato M, Martinez C, Keswick B (2008). Drinking water microbiological survey of the Northwestern State of Sinaloa, Mexico, *Journal of Water and Health*, 6(1), 125-129.

Dany V, Visvanathan C, Thanh NC (2000). Evaluation of water supply systems in Phnom Penh City: a review of the present status and future prospects, *International Journal of Water Resources Development*, 16(4), 677-689.

DWA (Department of Water Affairs), 2005 (2006). *A Drinking Water Quality Framework for South Africa*, Government Printer, Pretoria, South Africa.

ECR (1997). Environmental Conservation Rules, Bangladesh Gazette, Ministry of Environment and Forest, Government of the People's Republic of Bangladesh, 27 August 1997.

Egorov A, Ford T, Tereschenko A, Drizhd N, Segedevich I, 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.

Emmanuel E, Pierre MG, Perrodin Y (2009). Groundwater contamination by microbiological and chemical substances released from hospital wastewater and health risk assessment for drinking water consumers, *Environment International*, 35, 718-726.

Geldreich E (1996). Microbiological Quality of Water Supply in Distribution Systems, CRC Lewis Publishers, Boca Raton, Florida, USA.

Howard G, Bartram J (2005). Effective water supply surveillance in urban areas of developing countries, *Journal of Water and Health*, 03(1), 31-43.

Howard G, Ahmed MF, Shamsuddin AF, Mahmud SG, Deere D (2006). Risk assessment of arsenic mitigation options in Bangladesh, *Journal of Health Population and Nutrient,* 24(3), 346-355.

Howard G, Ahmed MF, Teunis P, Mahmud SG, Davison A, Deere D (2007). Disease burden estimation to support policy decision-making and research prioritization for arsenic mitigation, *Journal of Water and Health,* 5(1), 67-81.

Hunter PR, Chalmers RM, Hughes S, Syed Q (2005). Self-reported diarrhea in a control group: a strong association with reporting of low-pressure events in tap water, *Clinical Infectious Diseases*, 40(4), 32-34.

LeChevallier MW, Gullick RW, Karim MR, Friedman M, Funk JE (2003). The potential for health risks from intrusion of contaminants into the distribution system from pressure transients, *Journal of Water and Health*, 1, 3-14.

Lee EJ, Schwab KJ (2005). Deficiencies in drinking water distribution systems in developing countries, *Journal of Water and Health*, 3(2), 109-127.

Mermin JH, Villar R, Carpenter J, Roberts L, Samaridden A, Gasanova L, Lomakina S, Bopp C, Hutwagner L, Mead P, Ross B, Mintz ED (1999). A massive epidemic of multidrug-resistant typhoid fever in Tajikistan associated with consumption of municipal water, *Journal of Infectious Diseases*, 179(6), 1416-1422.

Mulamattathil SG, Bezuidenhout C, Mbewe M (2015). Analysis of physico-chemical and bacteriological quality of drinking water in Mafikeng, South Africa, *Journal of Water and Health*, 13(4), 1143-1152.

Nelson KE (2001). Early history of infectious disease: epidemiology and control of infectious diseases. In Infectious Disease Epidemiology: Theory and Practice K. E. (Nelson, C. Masters Williams & Graham N. M. H. eds). Aspen Publishers, Gaithersburg, Maryland.

Norstrom A (2007). Planning for Drinking Water and Sanitation in Peri-urban Areas, Swedish Water House Report 21, Swedish International Water Institute, Stockholm, Sweden.

NRPL (2004). National Resource Planners Limited, Survey Map Preparation of Khulna City Corporation, Final Report.

Okeke B, Thomson M, Moss E (2011). Occurrence, molecular characterization and antibiogram of water quality indicator bacteria in river water serving a water treatment plant, *Science of the Total Environment*, 409, 4979-4985.

Olsen SJ, Miller G, Breuer T, Kennedt M, Higgins C, Walford J, McKee G, Fox K, Bibb W, Mead P (2002). A waterborne outbreak of Escherichia coli 0157 infections and haemolytic uraemic syndrome: implications for rural water systems, *Emerging Infectious Diseases*, 8, 370-375.

Pathak SP, Gopal K (2008). Prevalence of bacterial contamination with antibiotic resistant and enterotoxigenic fecal coliforms in treated drinking water, *Journal of Toxicology and Environmental Health*, Part A, 71, 427-433.

Pereira V, Basilio M, Fernandes D, Domingues M, Paiva J, Benoliel M, Crespo M, Romão SM (2009). Occurrence of filamentous fungi and yeasts in three different drinking water sources, *Water Research*, 43, 3813-3819.

Pritchard M, Makandawire T, O'Neill J (2007). Biological, chemical and physical drinking water quality from shallow wells in Malawi: case study of Blantyre, Chiradzulu and Mulanje, *Physics and Chemistry of the Earth*, 32, 1167-1177.

Rahman A, Murtaza G (2003). Environmental Risk Management Action Plan for Khulna City Corporation, USAID, Dhaka, Bangladesh.

Semenza JC, Roberts L, Henderson A, Bogan J, Rubin CH (1998). Water distribution system and diarrheal disease transmission: a case study in Uzbekistan, *American Journal of Tropical Medicine and Hygiene*, 59(6), 941-946.

Tozzi AE, Caprioli A, Minelli F, Gianviti A, De Petris L, Edefonti A, Montini G, Ferretti A, De Palo T, Gaido M, Rizzoni G (2003). Shiga toxin-producing Escherichia coli infections associated with hemolytic uremic syndrome, Italy, 1988-2000, *Emerging Infectious Diseases*, 9, 106-108.

USEPA (2013). Coliform Bacteria in Drinking Water, United States Environmental Protection Agency (USEPA), Washington, DC.

WHO (1997). Guidelines for Drinking Water Quality, Volume 3: Surveillance and Control of Community Supplies, World Health Organization, Geneva, Switzerland.

WHO (2004). Guidelines for Drinking-Water Quality, 3rd Edition, World Health Organization, Geneva, Switzerland.

WHO (2006). Guidelines for Drinking Water Quality-Incorporating First Addendum, Recommendations, 3rd edition. World Health Organization, Geneva, Switzerland.

World Bank (2001). Managing Urban Water Supply and Sanitation: Operation and Maintenance, Operations Evaluation Department, World Bank, Washington DC, USA.

World Bank (2005). World Development Indicators, World Bank, Washington DC, USA.