Assessment of Surface Water and Groundwater Sources for Establishing Safe Urban Water Supply System in Faridganj Municipality, Bangladesh

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Abstract

Reliable water source having adequate water supply with acceptable quality is an essential component in any urban water supply system. In Bangladesh, urban water supply mainly depends on the conventional water sources, namely surface water from rivers and groundwater from aquifers. However, availability and quality of water from both sources often varies from place to place and should be assessed properly for establishing a safe water supply scheme. Hence, the aim of this study was to identify suitable water source for establishing a safe urban water supply scheme in Faridganj municipality of Chandpur district, Bangladesh using the mathematical modelling technique. Water demand was estimated for a 40 years (2001–2040) period based on the existing and projected populations in the municipality. Mathematical models were developed and simulated to assess the potential of surface water and groundwater sources to satisfy the water demand. For surface water source assessment, the South East Region Model (SERM) developed and maintained by Institute of Water Modelling (IWM), Bangladesh was used. The flow simulation was carried out by MIKE 11 software and surface water availability was assessed by analyzing the flow duration curve. For groundwater source assessment, the underlying aquifer in the municipality was demarcated based on the developed hydrostratigraphic sections from hydrogeological settings. The groundwater model was constructed and simulated in an integrated MIKE 11 and MIKE SHE platform, which covered 10716 km^2 area including six districts in the south-east region of Bangladesh. The simulation and water quality test results indicated that both surface water and groundwater sources were found satisfactory in terms of quantity and quality to meet the existing and projected water demand in Faridganj municipality. Therefore, the present study concludes that the existing surface water and groundwater sources are sufficient for establishing the safe urban water supply scheme in Faridganj municipality, Bangladesh.

1. INTRODUCTION

Establishing safe water source is a priority issue for any urban water supply scheme. Adequate supply of water with acceptable quality is one of the most challenging tasks to the urban development authorities in the developing world, which is an important concern for sustainable urban development (Karim & Mohsin, 2009). Nowadays, the development activities of a country are related to its water consumption. However, the freshwater demand continues to grow with the increasing population and development activities. The situation is more challenging in the urban part of a country (Garcia *et al*., 2008).

United Nations has predicted that in the next decades, about 56% of total population of the developing countries will be resided in the urban areas (UNEP, 2002). In Bangladesh, urban population is also increasing rapidly following its natural urban growth and migration from the rural areas (Karim & Mohsin, 2009). An estimation by the Bangladesh Bureau of Statistics (BBS) indicates that the urban population in the country was about 38 million in 2005, and is expected to be doubled by 2040 (BBS, 2010). Such growth of urban population will certainly induce a remarkable burden on the country‟s target of providing safe water supply and adequate sanitation facilities to the people. This may impact on the live of a large number of people without access to safe water supply and adequate sanitation facilities particularly in the urban areas of the country.

Water management in an area should be based on the proper knowledge of available surface water and groundwater systems (Garcia *et al*., 2008). In Bangladesh, conventional water sources (i.e., the rivers and underlying aquifers) are mainly used for municipal water supply. However, water quantity and quality limitations of these sources often impose economic constraints on the system operation requiring additional treatment costs including development of more expensive alternative sources in the system (Shah & Khan, 2008). About 97% of rural population and a major portion of the urban population in Bangladesh depend exclusively on the groundwater source. However, it has been discovered in 1993 that the groundwater source is affected by the arsenic pollution in some parts of the country. Furthermore, the surface water sources are usually polluted and require suitable treatment before use (Das Gupta *et al*., 2005). Therefore, identification and establishment of a safe drinking water source is a very challenging task in Bangladesh.

The national water policy of Bangladesh has declared that all necessary means and measures should be taken to manage the water resources of the country in a comprehensive, integrated and equitable manner (WaRPO, 1999). In order to achieve this goal, various authorities have been working towards safe water supply to the people. Water supply coverage of Dhaka Water and Sewerage Authority (DWASA), Chittagong Water and Sewerage Authority (CWASA), Khulna Water and Sewerage Authority (KWASA) and Rajshahi City Corporation (RCC) is 83%, 34%, 25%, 84%, respectively. Among 309 municipalities in Bangladesh, only 102 municipalities have intermittent piped water supply that has average coverage of 39% and the rest has no piped water supply system (World Bank, 2009). Hence, the overall objective of this study is the assessment of existing surface water and groundwater sources to identify the safe water source for establishing a safe urban water supply scheme in the Faridganj municipality, Bangladesh, which has currently no piped water supply system.

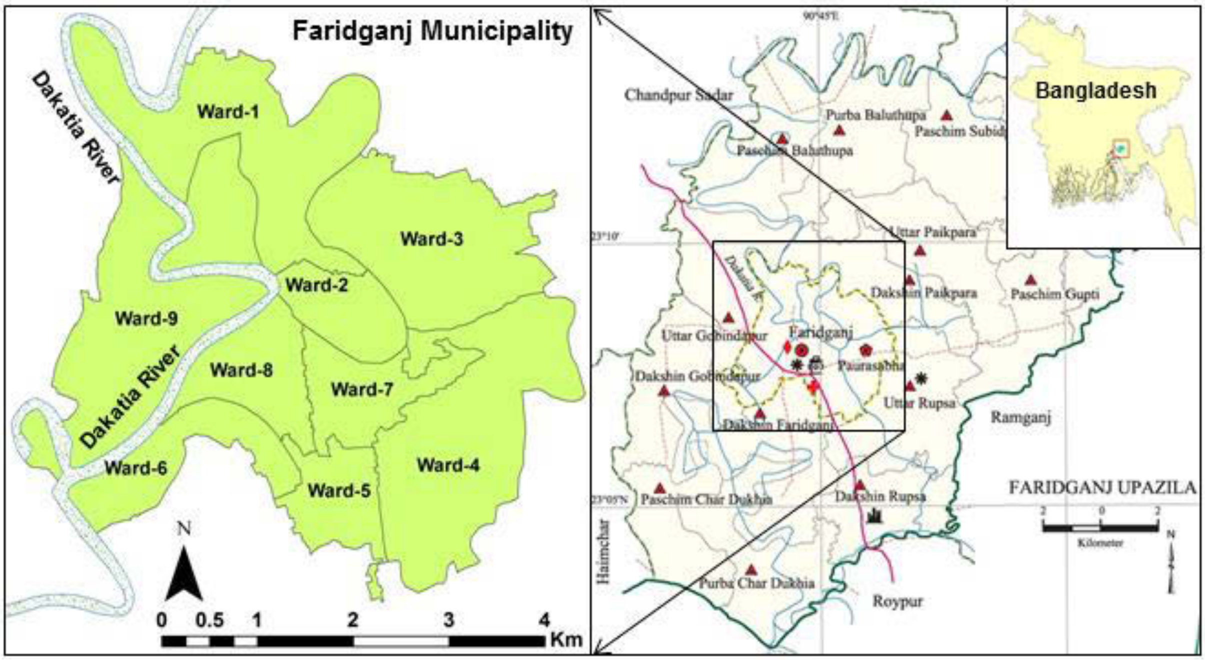

Figure 1 Location of the study area (Faridganj muncipality) in Bangladesh

2. STUDY AREA DESCRIPTION

The present study is carried out for the Faridganj municipality in Faridganj upazilla (sub-district) under Chandpur district, Bangladesh as shown in Figure 1. The municipality is located at 15 km southeast from the Chandpur district headquarters under Chittagong Division. It consists of nine wards covering an area of 20.74 km^2. The Dakatia River is flowing along the western boundary of the municipality. Only ward-9 is situated to the left bank of Dakatia River. The municipality was established in 2005 and categorized as a „C-class" municipality.The population has been increasing since its inception. Although the relative importance of the municipality has been growing as a regional center of trade and commerce, currently it has no piped water supply facilities. At present, shallow hand tube well is the only source of water supply for the dwellers and there are about 2368 hand tube wells in the municipality. All shallow tube wells are privately operated. 90% of hand tube wells are free from arsenic but most of the hand tube wells are contaminated with iron. There is no rain water harvesting (RWH) facility in practice in the municipality. The municipality has no deep production tube well of its own. The municipal authority is now planning to establish a piped water supply system, which has motivated a detailed assessment study for the surface water and groundwater sources.

3. WATER DEMAND ASSESSMENT

In this study, a comprehensive water demand assessment was performed for the baseline year 2010, and was projected up to the design year 2040. Both spatial and non-spatial information were considered in the demand assessment. GIS-based spatial maps and demographic characteristics of the study area are used for this purpose. GIS maps were generated based on the topographic survey data conducted by Institute of Water Modelling (IWM) in 2010. However, demographic information were taken from the population census reports of BBS for the years 1981, 1991 and 2001. For the baseline year 2010, demographic data were obtained from the social impact assessment (SIA) survey of IWM. The population projection was then performed for the municipality and per capita water demand was assigned to the population in the municipality area. For population projection, the most widely used geometric progression method was used in this study. The water required for backwashing of the water treatment plant (WTP) was added to the domestic water demand to compute the final water demand in the municipality. The backwash water was taken as a percent fraction of the water demand in the final demand estimation. This estimation process was repeated for every five years from 2010 to 2040, and the findings are shown in Table 1.

Table 1. Projected attributes and water demand in Faridganj municipality, Bangladesh

Description of attributes	Year						
	2010	2015	2020	2025	2030	2035	2040
Population (nos.)	39719	43045	46666	51863	56262	62777	68147
Water demand (m^3/d)	897	1263	1738	2652	3802	5460	7480
Water demand & WTP backwash (m^3/d)	945	1335	1843	2821	4057	5845	8035

4. ASSESSMENT OF SURFACE WATER SOURCE

4.1. South East Regional Model

Six regional models have been developed and maintained by IWM, Bangladesh, which cover the whole country, namely South West Regional Model, North West Regional Model, North Central Regional Model, North East Regional Model, South East Regional Model and Eastern Hill Regional Model. The South East Regional Model (SERM) of Bangladesh was developed primarily for planning studies of the secondary rivers in the regional model, which covers the major river networks of the south east region of Bangladesh. Faridganj municipality is located on the bank of the Dakatia River in the south east region of Bangladesh. Assessment of surface water availability for the municipality water supply was carried out from the potential source of nearby Dakatia River analyzing the South East Regional Model (SERM) results. The SERM includes the greater Comilla, Chandpur, and Noakhali districts with an area of 8500 km^2, which is regularly calibrated and validated by IWM. This study used the latest simulation results obtained from the updating and validation of the SERM for

2002-2003 hydrological year. A sample plot of the calibrated water level in the Dakatia River at Hajiganj (Station ID: Dakatia 81275) of Faridganj municipality is shown in Figure 2a. Figure 2b shows the simulated discharge in the Dakatia River at Hajiganj (Station ID: Dakatia 81637.50) of Faridganj municipality.

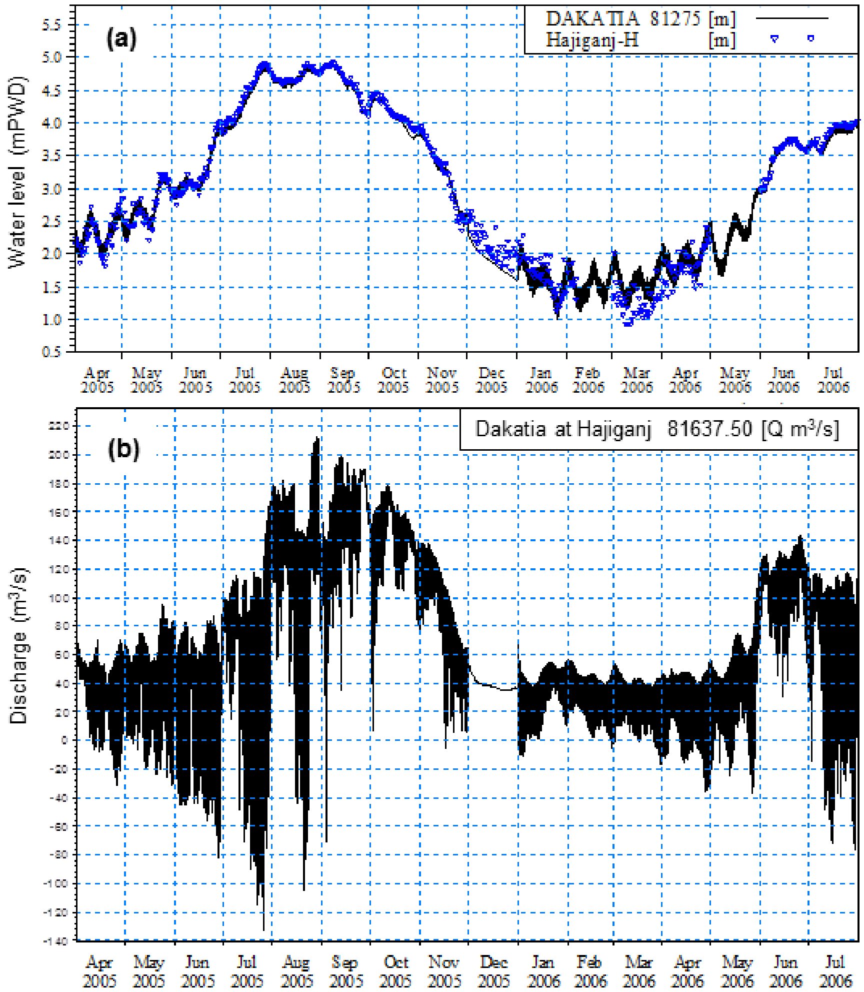

Figure 2 (a) Calibrated water level and (b) simulated discharge on the Dakatia River at Hajiganj point in Faridganj municipality

4.2. Assessment of Surface Water Availability

Surface water availability was assessed by the dependable flow analysis, which was based on the flow duration curve (FDC) developed from simulated discharge at Hajiganj point in Faridganj municipality. FDC is a plot of discharge versus percent time the flow is equalled or exceeded. The discharge at a percentage of probability in FDC represents the flow magnitude in an average year that can be expected to be equalled or exceeded.

In this study, Weibull method of FDC (Chow *et al*., 1988) was adopted for the dependable flow analysis. This method determines the desired value (i.e. dependable flow) by ranking the daily flows in descending order and assigning each with an exceedance probability. The simple plotting system is expressed by the Weibull plotting position formula as expressed by the Equation (1).

$$P(X \geq x_m) = \frac{m}{n+1} \tag{1}$$

Where, P is the probability of exceedance; m is the rank number from 1 to n, and n is the number of ranked flows. This method was chosen over several available plotting position formulas in statistics (Chow *et al*., 1988) because of its simplicity in use and easy adaptability to computers. Dependable flows were computed for the year round analyses for the period of 1985 to 2009 for Faridganj municipality and are given in Table 2.

Table 2. Dependable flows for the Dakatia River at Faridganj municipality

Location	River	Dependable flow for the dry season (m^3/s)		
		50%	80%	90%
Faridganj	Dakatia	40.08	19.38	12.69

The required surface water withdrawal to meet the demand in the municipality is 0.093 m^3/s (8035 m^3/d) in the year 2040 (Table 1). However, available surface water from the Dakatia River is found as 1004832 m^3/d. Moreover, the river flow is available round the year. Detailed calculation of the dependable flow analysis is shown in Box 1. The analysis and results indicate that dependable flow in Dakatia River is capable of meeting the water supply demand of Faridganj municipality all through the year. Hence, it can be concluded that surface water source is adequate to fulfill the water supply demand in Faridganj municipality and seems to be an appropriate option for long-term water supply.

Box 1. Calculation details for dependable flow analysis for Faridganj municipality

Required surface water withdrawal for the municipal water supply	= 0.093 m^3/s
80% dependable flow (from available water) of the Dakatia River	= 19.38 m^3/s
Available water in the Dakatia River after withdrawal for water supply	= 19.29 m^3/s
Exploitable flow (60% of 80% dependable flow)	= 11.63 m^3/s
Environmental flow requirement (40% of 80% dependable flow)	= 7.75 m^3/s
Available surface water for the municipal water supply	= 1004832 m^3/d
Water availability in the Dakatia River	= 12 months

4.3. Evaluation of Surface Water Quality

Assessment of surface water quality was carried out based on the primary water sampling data collection period at the selected locations of the Dakatia River in Faridganj municipality. The laboratory testing was performed in the Department of Public Health Engineering (DPHE) central lab, Dhaka. The test results shown in Table 3 indicate that only two parameters such as Biochemical Oxygen Demand (BOD_5) and Chemical Oxygen demand (COD) are not within allowable limit of Bangladesh drinking water standard (ECR, 1997). Furthermore, the microbial test was not performed. Therefore, it is strongly recommended that regular monitoring and laboratory analysis of surface water quality is necessary for undertaking subsequent treatment scheme. Hence, it can be concluded that the Dakatia River can be used as a safe water source for municipal water supply in Faridganj municipality only after suitable treatment for BOD and COD as well as for the microbial parameters.

Table 3. Status of surface water quality of the Dakatia River at Faridganj municipality

Sl. No.	Parameter	Unit	Bangladesh Standard (ECR, 1997)	Measured value
1	pH	-	6.5-8.5	5.8
2	BOD_5	mg/L	**0.2**	**3**
3	COD	mg/L	**4**	**22**
4	Turbidity	NTU	10	4.83
5	NH_3	mg/L	0.5	0.23
6	NH_4	mg/L	0.5	0.21
7	NO_3	mg/L	10	0.29
9	NO_2	mg/L	<1.0	<0.016
10	TDS	mg/L	1000	44
11	TSS	mg/L	10	7.75
12	PO_4	mg/L	6	1.05
13	SO_4	mg/L	400	4
14	Pb	mg/L	0.05	0.042
15	Cr Total	mg/L	0.05	0.0002
16	Cl-	mg/L	150-600 (max. 1000)	12

5. ASSESSMENT OF GROUNDWATER SOURCE

5.1. Hydrogeology and Aquifer Setting

In Bangladesh, groundwater is usually considered an acceptable source because its quality simply meets the drinking water standard and thus, little or no treatment is necessary (Adhikary *et al.*, 2011). In this study, assessment of groundwater source was based on two major tasks: hydrogeological studies and aquifer demarcation, and simulation of groundwater system. Hydrogeological investigation was performed to delineate the hydrostratigraphic layers in Faridganj municipality. Sub-surface lithological characterization and formation of hydrostratigraphic units were produced by analyzing the individual lithological units and depth of different aquifers from the available thirteen lithological borelogs in the study area. IWM customize software “depth-storage model” was used to generate the hydrostratigraphic columnar sections and determine the specific yield of sediment formation. The columnar sections produced from borelogs indicate the top most clay layer varying in depth from place to place and a productive aquifer exists below the alteration of aquitard and aquiclude layers. By analyzing the stratigraphy of the study area, major hydrostratigraphic units are delineated accordingly and average thickness of individual hydrostratigraphic unit are presented in the Table 4. As can be seen in Table 4, the uppermost layer is aquiclude and below the aquiclude layer, three composite layers of aquifer are evident within different depth and separated by clay layer. A prominent aquifer is evident just below the composite layer having thickness of 45m and pinched out at Char Mathura in the study area. Specific yield of this aquifer varies from 0.03 to 0.18 indicates that the aquifer consists of fine to medium sand. The storage coefficient, columnar section of borelogs and hydrostratigraphic sections indicate that the aquifer is semi-confined in nature.

Table 4. Outline of hydrostratigraphic units and their extents in Rangunia municipality

Hydrostratigraphic Unit	Depth (m)	Average Thickness (m)
1^{st} Aquiclude	0 - 12	12
1^{st} Aquitard	5 - 35	30
1^{st} Composite Aquifer	15 - 80	65
2^{nd} Aquiclude	75 - 120	45
2^{nd} Composite Aquifer	80 - 140	60
3^{rd} Aquiclude	135 - 165	30
3^{rd} Aquitard	140 - 180	40
3^{rd} Composite Aquifer	165 - 220	55
1^{st} Aquifer	220 - 265	45

5.2. Numerical Simulation of Groundwater Source

For the assessment of groundwater source, large numbers of hydrogeological and meteorological (rainfall) data were collected. For hydrogeological study and groundwater assessment, specific emphasis was given for the municipality area and its vicinity. For groundwater modelling in this study, a larger model domain was considered to avoid the boundary influences in model computations (Anderson & Woessner, 1992). The groundwater model was constructed in MIKE-SHE (DHI, 1999) software platform. MIKE-SHE is a comprehensive mathematical modeling system that covers the entire land-based hydrological cycle, simulating surface flow, infiltration, flow through the unsaturated zone, evapotranspiration, and groundwater flow. Major components of the model setup include evapotranspiration, unsaturated zone, saturated zone, overland flow and river systems. The default time step control and computational control parameters for overland flow, unsaturated zone and saturated zone were used for entire simulation period.

The model domain covers an area of about 10716 km^2, which was discretized into 1 km square grids. It consists of 4812 grid cells in each layer where 239 cells are the boundary cells and the rest are the computational cells. The grid cells are the basic units to input all the spatial and temporal data and obtain the corresponding output. The coupling of surface and groundwater systems involves a number of specifications. The river reaches where the coupling will take place was defined in the river model. In this study, all the major rivers and small streams (locally named as Khals) in the study area were coupled with the aquifer. All forms of river-aquifer exchanges and the flooding conditions were also defined. The flow exchange between the SZ component and the river component mainly depends on the head difference between river and aquifer, and riverbed material properties such as leakage coefficient. For river-aquifer dynamic flow exchange, leakage coefficients along with the hydraulic conductivity of the SZ were taken into account for most of the river reaches. The developed model was then calibrated and validated against the observed groundwater head for 1998-2005 and 2006-2009 periods, respectively. During calibration phase, overland leakage coefficient, vertical hydraulic conductivity, storage coefficient and river leakage coefficient were adjusted. After successful calibration and validation, the groundwater model was used for the simulation of groundwater flow.

5.3. Assessment of Groundwater Availability

Available groundwater resource was estimated based on the well-known groundwater fluctuation technique (Healy and Cook, 2002) using the simulated head distribution in the study area. The data analysis suggests that only two geological layers exist within 7m depth (i.e., 6m and 7m). Saturated thickness of first and second layers were multiplied by the corresponding specific yield (S_Y) values and summed up to obtain the depth of available water in a model grid. Groundwater storage in volumes was estimated by multiplying the available water depth of the grid (volume of water = area x Δh x S_Y, where Δh is the saturated thickness within 6m and 7m depths). Total available groundwater resource was then calculated based on the number of grids lying within the study area. Finally, groundwater resource availability was assessed in 2002 at base condition (selected from return period analysis of rainfall) for two different depths (within 6m and 7m) within Faridganj municipality. The available groundwater for these two different depths is found as 11.4 Mm^3 (million cubic meters) for 6m depth and 13.3 Mm^3 for 7m depth, respectively. In this study, the 6m and 7m depths were used for the unconfined aquifer to calculate the available groundwater within the limit of suction mode pump. The long-term (40 years) simulation indicates that the groundwater will be lowered down by 0.5m after ten years of continuous withdrawal, which is a certain threat to the aquifer sustainability. Therefore, conjunctive utilization of surface and groundwater is strongly recommended for establishing the safe water supply scheme in the Faridganj municipality.

5.4. Assessment of Water Quality

Groundwater quality data of deeper groundwater at Faridganj test tube well was not collected because test tube well installation was not completed. Consequently, groundwater samples were collected from an existing DPHE well and the test results are presented in Table 5. Table 5 results indicate that almost all the parameters are within the allowable limit of Bangladesh drinking water standard. However, Barium exceeded the allowable limit and hence the groundwater only requires some treatment. Therefore, it can be concluded that groundwater source can be used as a suitable source for urban water supply in Faridganj municipality with appropriate treatment before consumption.

Table 5. Status of the groundwater quality of the underlying aquifer in Faridganj municipality

Sl. No.	Parameter	Unit	Bangladesh Standard (ECR, 1997)	Measured value
1	Arsenic (As)	ppb	50	6
2	Barium (Ba)	ppb	**10**	**40**
3	Aluminium (Al)	mg/L	0.20	0.04
4	Boron (B)	mg/L	1.0	0.04
5	Calcium (Ca)	mg/L	75.0	28.1
6	Iron (Fe)	mg/L	0.3-1.0	0.586
7	Manganese (Mn)	mg/L	0.10	0.051
9	Magnesium (Mg)	mg/L	35.0	17.7
10	Chloride (Cl)	mg/L	150-600	-
11	Copper (Cu)	mg/L	1.0	0.008
12	Fluoride (F)	mg/L	1.0	-
13	Sulphate (SO_4)	mg/L	400	0.6
14	Potassium (K)	mg/L	12.0	3.9

6. CONCLUSIONS

This study assesses the conventional water sources (surface water rivers and groundwater aquifers) in order to identify the potential safe water source for establishing a safe water supply system in the Faridganj municipality of Bangladesh. Based on the predicted population and proposed water supply scheme in Faridganj municipality, the projected water demand has been estimated as 8035 m^3/d in the design year 2040. The assessment indicates that both surface and groundwater sources have sufficient availability of water to meet the demand up to the design year 2040 in the municipality. Surface water and groundwater quality was also within acceptable limit except very few parameters. Therefore, minor treatment is necessary for those parameters to maintain the drinking water quality standard. Finally, the study recommends that conjunctive use of water from both surface and groundwater sources as well as regular monitoring of the water quality parameters should be carried out for establishing a safe and sustainable water supply scheme in the Faridganj municipality in Bangladesh.

7. ACKNOWLEDGMENTS

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