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IDENTIFICATION AND ASSESSMENT OF EXISTING WATER SOURCE FOR SUSTAINABLE MUNICIPAL WATER SUPPLY IN BANGLADESH - A CASE STUDY

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ABSTRACT: Sustainability of any urban water supply scheme mainly depends on the appropriate assessment of available surface water (SW) and groundwater (GW) resources from the existing conventional water sources such as the rivers and underlying aquifers. The overall objective of this paper is to identify as well as to assess the applicability of available conventional water sources for sustainable water supply in municipality level with the help of mathematical modelling technique. Muksudpur municipality under Muksudpur upazilla of Gopalganj district in Bangladesh has been considered for this case study. Water demand in the municipality is estimated up to the design year 2040 by using the population census data. Assessment of SW and GW sources is done by developing and simulating mathematical models for the present and projected water demand scenarios. For evaluating the existing SW source, the South West Regional Model (SWRM) developed by Institute of Water Modelling (IWM) in Bangladesh is applied. In SW model, the flow simulation is executed by using MIKE-11 software. Water availability assessment for the municipal water supply is carried out from the long-term simulated discharge (comprising 20-years model run) from the validated model available at IWM. However, the underground aquifer system is delineated with the help of hydrostratigraphical columnar sections based on the hydrogeological and lithological setting in the case study area and its surroundings. Integrated MIKE-11 and MIKE-SHE software platform has been used for developing and simulating the GW model. The developed GW model spreads over 34 upazillas in southwestern Bangladesh. The analysis and modeling result demonstrates that Muksudpur municipality has available water resources from both the SW rivers and GW aquifers to supply drinking water up to the design year 2040. Therefore, both sources are quite sufficient to meet the required water demand at present as well as in future. However, water quality results of both sources indicate that they can be safely used for water supply in Muksudpur municipality of Bangladesh with little or no treatment.

Keywords: *Aquifer, Bangladesh, Flow Duration Curve, Groundwater Modelling, Muksudpur Municipality, Mathematical Modelling, MIKE-11, MIKE-SHE, Water Source, Water Supply*

1. Introduction

Supply of adequate water with acceptable quality in the urban areas is one of the challenging tasks to the urban development authorities in developing countries. It is a very important requirement and consideration for sustainable urban development (Karim & Mohsin, 2009). Thus, development activities nowadays in a country are related to its water consumption. Globally, water demand continues to grow up with the increasing population and development activities (Garcia et al., 2008). However, there has been a growing trend of population settlement in urban areas over the last half-century especially in developing countries. The ever-increasing

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demands of water, land, ecosystems along with other resources from the additional populations will pose tremendous challenges in the delivery of food, water, and energy for municipal and industrial purposes. Expected potential impacts of climate change will further exacerbate the challenges facing planners and providers of such services. Therefore, establishing sustainable water supply scheme along with other services in growing towns and cities remains an important issue. According to United Nations prediction, about 56% of the people in developing countries will be resided in urban areas (UNEP, 2002). Urban population in Bangladesh is also increasing rapidly because of the natural urban growth and migration from rural areas. The current urban population in the country is about 38 million and will be reached to about 74 million by 2035 (BBS, 2005). Such growth of urban population will certainly add a significant burden on urban water supply and sanitation facilities causing a large number of people live without access to safe water supply and adequate sanitation in urban areas.

Bangladesh is sub-divided into total 309 municipalities (Paurashavas). Outside of Dhaka and Chittagong, each municipality is responsible for its own water supply, sewerage, and storm drainage. Among them, only 102 municipalities have intermittent piped water supply facilities with an average coverage area of 39% and rest of them has no piped water supply facilities (Amin & Hasan, 2011). In Bangladesh, municipal water supply systems generally depend upon surface water (SW) and groundwater (GW) sources. However, water quantity and quality limitations of the sources often impose economic constraints on system operation requiring additional treatment costs (Nobi & Das Gupta, 1997; Shah & Khan, 2008). SW source is often polluted in Bangladesh due to human excreta as well as urban and industrial pollution and therefore, it requires necessary treatment scheme before consumption. GW is the main source of freshwater supply in the country, as it needs little or no treatment. However, in 1993 arsenic contamination had been discovered in the GW source, which puts a limitation of its consumption (Das Gupta et al., 2005). Therefore, identifying safe drinking water source is a major challenging task in Bangladesh. In this study, Muksudpur municipality in Bangladesh is has been considered as a case study area and a detailed study is performed to establish safe water source for developing the water supply network by using the mathematical modelling technique. It is the only urban area of Muksudpur upazila under Gopalganj district and presently, classified as a “C-category” municipality. It was established on 2000 and its population has been increasing since its inception. Although the relative importance of the municipality has ever been growing as a regional centre of trade and commerce, it has no piped water supply system at present. Therefore, this study is a preliminary attempt to assess the existing SW and GW sources to identify safe water source for establishing long-term sustainable water supply options to the dwellers of Muksudpur municipality under Gopalganj district in Bangladesh. This study may open a window of opportunity for the appropriate development of SW and GW resources in Bangladesh.

2. Existing Water Sources and Supply Practices in Muksudpur Municipality

Muksudpur municipality is situated at 25 km. north from Gopalganj district head quarters, in Muksudpur upazilla of Gopalganj District under Dhaka Division in Bangladesh. It is comprised of nine wards. The Kumar River is flowing through the municipality, where stagnant water is usually available throughout the year. Although river water is turbid, due to its year round availability, it can be utilized for water supply purpose in the municipality with little treatment.. There are five drainage channels namely Kamalapur Khal, Kamalapur Branch Khal, Chakrabarti Khal, WAPDA Khal and Tengrakhola Khal, where water is available only in monsoon. There are 75 ponds, 50% of which contains water round the year. At present, shallow hand tube wells (HTW) are being used by the local people to abstract water from underground aquifer. The water table in the municipality area is 5.40m during low water season. There are about 2500 HTWs in the study area, out of which 240, 250 and 50 nos. have been installed by DPHE, municipal authority, and NGO, respectively. 90% HTWs are contaminated with arsenic and 50% HTWs are contaminated with iron content. There is one GW monitoring well belonged to BWDB. There is no rainwater harvesting (RWH) facility in the municipality. The river water has been identified as source of drinking water to the dwellers of Muksudpur municipality.

3. Assessment of Water Demand

In this study, a comprehensive water demand assessment is carried out for the baseline year and is projected up to the design year 2040. The demand assessment technique includes both spatial and non-spatial information. GIS-based map of the study area is the spatial data and non-spatial data input includes the demographic characteristics.

Table 1 Projected attributes of Muksudpur municipality

Description	2010	2015	2020	2025	2030	2035	2040
Growth rate	2.276	2.243	2.210	2.178	2.147	2.116	2.085
Population	21,159	23,641	26,372	29,990	33,351	37,950	42,075
Water demand (m^3/d)	463	674	956	1,491	2,194	3,208	4,492
Water demand + WTP backwash (m^3/d)	488	712	1,014	1,586	2,341	3,434	4,825

GIS maps are prepared based on the topographic survey data conducted by IWM in 2010. However, demographic information is collected from the population census reports of Bangladesh Bureau of Statistics (BBS) for the years 1981, 1991 and 2001. For the baseline year 2010, demographic data are obtained from the social impact assessment (SIA) survey. The projection of population in the municipality is done and then per capita demand for growing cities is assigned to the population according to the land use category in the municipality area. This process is repeated for every five years from 2010 to 2040 and the findings are presented in Table 1.

4. Assessment of Surface Water Source

4.1. *Modelling of surface water resources*

In Muksudpur municipality, conventional source of water for drinking is either from SW or GW source. Perennial rivers, reservoirs, lakes and ponds form the SW source, while underground aquifer constitutes the GW source. Both the sources have limitations such as water availability, water quality environment, physical locations, hydrogeology, salinity, etc. In order to identify the safe drinking water sources, several variables need to be looked at. Therefore, the mathematical model for both SW and GW systems are used to solve this multifaceted problem for satisfying the present and projected safe drinking water requirement in the municipality. Assessment of existing SW for supplying water into Muksudpur municipality is carried out based on the potential sources from the nearby Kumar River. The municipality is situated on the bank of the Kumar River in the South West Region (SWR) of Bangladesh. The Kumar River is a spill channel from the Padma River, regulated at the upstream, with relatively less discharge that reduces significantly during the dry season.

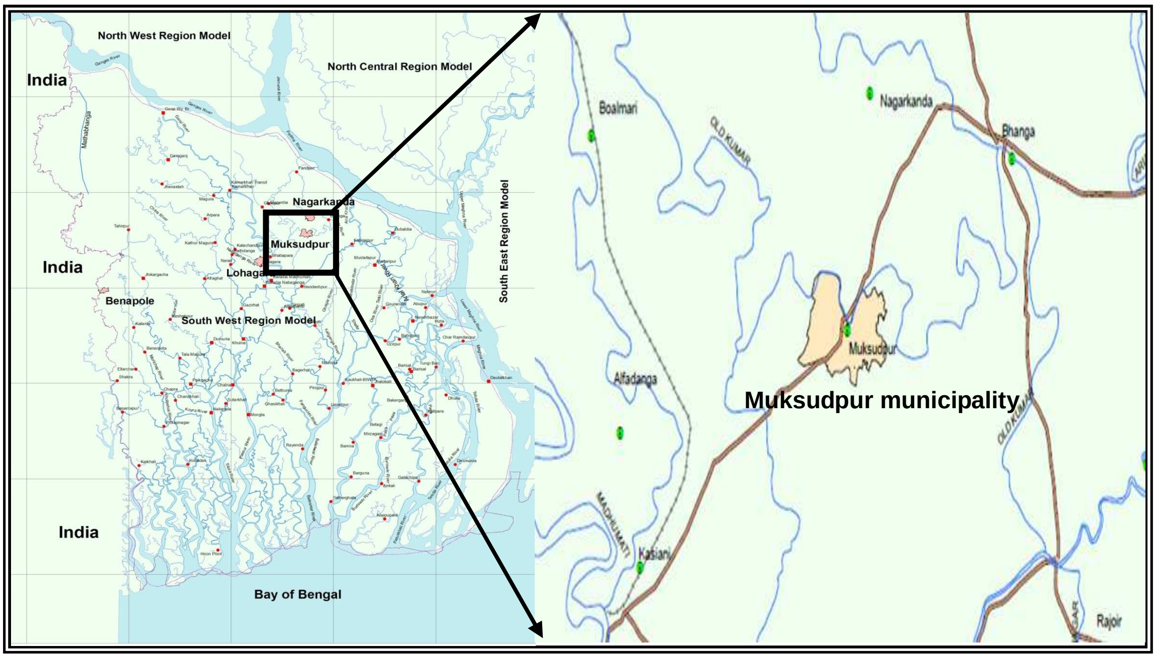

Figure 1 Location of Muksudpur municipality (study area) in SWRM of Bangladesh

However, flow in Kumar River is continuous with pockets of water all throughout the reach. The flows in the Kumar River, along with water from impounding reservoir, can be used as a sustainable SW source after a detailed level of study for SW treatment plant, which can supply drinking water to the municipality dwellers. The intake point of Muksudpur municipality is located in the South West Region Model (SWRM) developed earlier by IWM. Water availability assessment for the municipality is carried out from long-term simulated discharge (comprising of 20-years model run) of validated model available at IWM. Data collection as well as updating and validation of models are carried out by IWM each year.

4.2. ***Assessment of south west regional model***

The South West Region Model (SWRM) covers the entire area lying to the south of the Ganges and west of the Meghna estuary. It was developed at IWM mainly for planning studies of the secondary rivers in the regional model (Figure 1). It includes the major river networks of the SWR of the country covering the administrative divisions of Barishal and Khulna. The river systems around Muksudpur municipality are presented in Figure 1. The SWRM is one of the six regional models in Bangladesh developed under erstwhile Surface Water Simulation Programme, Phase-II (SWSMP-II). The development of the model was initiated in December 1989 and data collection was initiated in April 1990. The present model was primarily conceived as Pilot Models for two sub-regions, such as the South West and the South Central models, which were later developed into full-scale models. The present model was developed as a single regional model developed towards the end of SWSMP-II upon merging of the two separate models mentioned above into a single model commonly referred to the SWRM. In this study, the whole model is calibrated and validated based on 20 years historical data and is used to predict water resource availability for supplying drinking water in Muksudpur municipality. A sample plot of water level calibration for the Kumar River at Upstream near Muksudpur is presented in Figure 2.

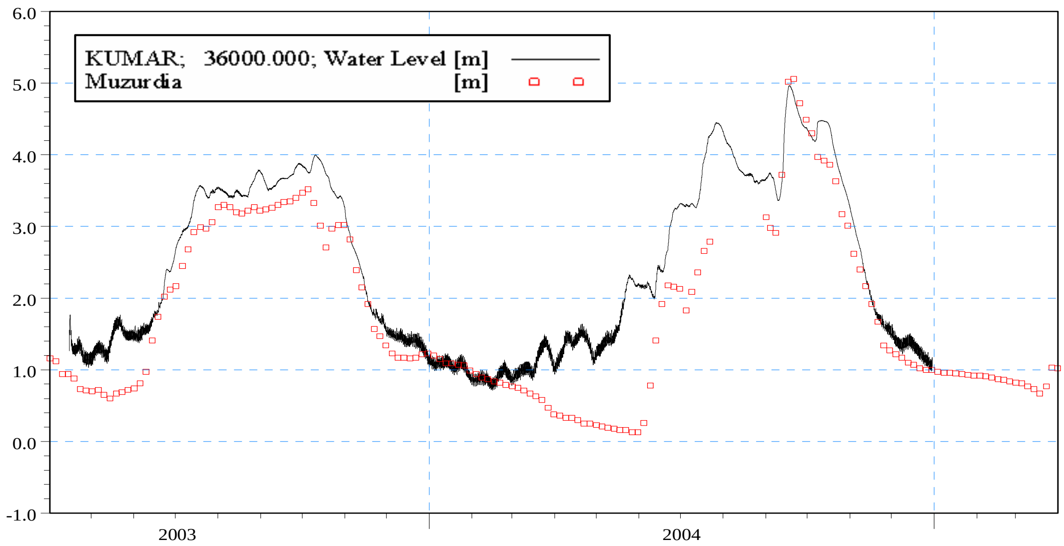

Figure 2 Calibrated water level of the Kumar River near Muksudpur

4.3. *Surface water availability assessment*

Available SW resource of Muksudpur municipality is estimated from long-term (comprising of 20-years model run) simulated discharge of validated model available at IWM. The assessment is based on flow duration curve (FDC) developed (Figure 3) from simulation data for year round discharge at the selected station. The discharge at any percentage of probability in FDC represents the flow magnitude in an average year that can be expected to be equalled or exceeded. Dependable flows have been computed for year round analyses for the period of 1985 to 2009 for Muksudpur municipality and are presented in Table 2. The water demand of the municipality by considering the additional requirement of a water treatment plant (WTP) for its backwashing is estimated as 0.0558 m^3/s (4,825 m^3/d) or 55.80 L/s (Table 1).

Table 2 Dependable flow analysis by FDC of the Kumar River at Muksudpur

Location	River name	Dependable flow for the dry season (m^3/s)		
		50%	80%	90%
Muksudpur	Kumar	0.6	0.275	0.2

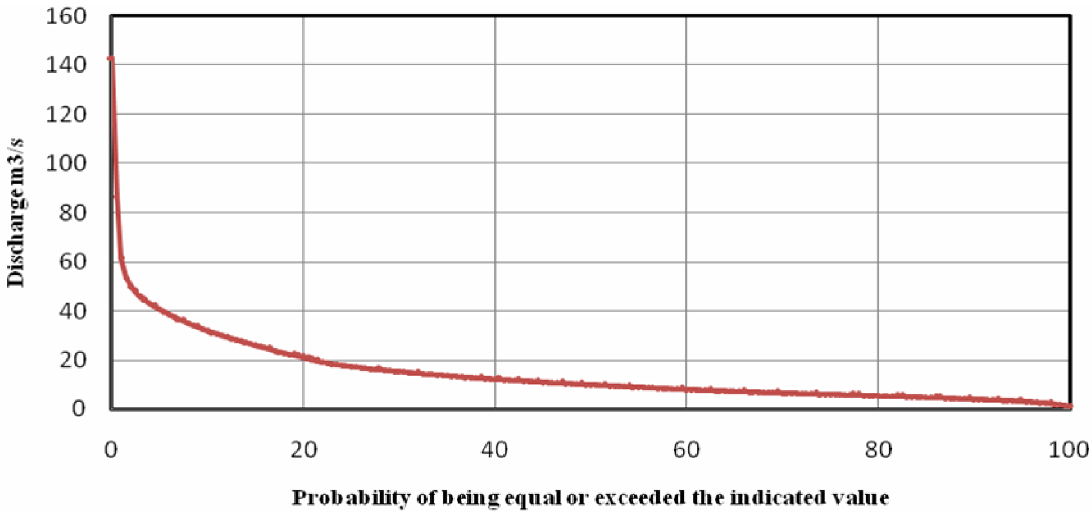

Figure 3 Flow duration curve (FDC) for the Kumar River at Muksudpur

Required SW withdrawal for Muksudpur municipality	= 0.0558 m^3/s
80% dependable flow (from available water) of the Kumar River	= 0.2750 m^3/s
Available water in the Kumar River after withdrawal for water supply	= 0.2192 m^3/s
Exploitable flow (60% of 80% dependable flow)	= 0.1650 m^3/s
Environmental flow requirement (40% of 80% dependable flow)	= 0.1100 m^3/s
SW availability for the dwellers in Muksudpur municipality	= 14,256 m^3/d
Estimated withdrawal necessary for Muksudpur municipality	= 4,825 m^3/d

Therefore, sufficient SW resource is available to fulfill the water demand of the consumers in Muksudpur municipality under Gopalganj district of Bangladesh.

4.4. *Analysis of surface water quality*

Water quality assessment (Table 3) is carried out based on the primary water sampling data collection session conducted at the selected locations on the Kumar River near Muksudpur municipality. The rainfall and subsequent river stage and discharge remain quite low during the initial stage of the year 2010 and thereby the pre-monsoon water quality sampling has been done in June 2010. The test results of the collected samples are presented in Table 3. The test results demonstrate that water quality of Kumar River at Muksudpur is within the allowable limit for almost all parameters for pre-monsoon period. However, the water-sampling mission is carried out in May 2011 (pre-monsoon period) since the water quality is at the most deteriorated level in that time. Therefore, the river water (SW source) can be a safe drinking water source for municipal water supply in Muksudpur municipality. Nevertheless, it is emphasized that regular monitoring and laboratory analysis and subsequent treatment scheme is necessary for sustainable water supply.

Table 3 Measured river water quality of the Kumar River at Muksudpur

Sl.	Parameters	Unit	Allowable Limit for Drinking Water (ECR, 1997)	Measured Value Pre-Monsoon
1	pH	-	6.5-8.5	7.1
2	BOD_5	mg/L	0.2	4
3	COD	mg/L	4	<4
4	Turbidity	NTU	10	0.8
5	NH_3-N	mg/L	0.5	< Limit of Quantization
6	NH_4-N	mg/L		< Limit of Quantization
7	NO_3-N	mg/L	10	0.05
8	NO_2-N	mg/L	< 1.0	<0.016
9	TDS	mg/L	1000	163
10	TSS	mg/L	10	3.5
11	PO_4-P	mg/L	6	0.64
12	Cr_{Total}	mg/L	0.05	0.002
13	Pb	mg/L	0.05	0.039
14	Cl^-	mg/L	150-600 (maximum 1000)	51
15	SO_4-S	mg/L	400	20
16	Hg	mg/L	0.001	< Limit of Quantization

5. Assessment of Groundwater Source

5.1. *Analysis of lithological setting and delineating aquifer system*

In Bangladesh, GW is generally regarded as an acceptable source because its quality is usually in the range of drinking water standard and little or no treatment is necessary. In this study, GW source assessment is performed based on two major tasks such as hydrogeological studies and GW modelling and simulation. Hydrogeological investigation has been carried out to define the hydrostratigraphic layers in Muksudpur municipality. Sub-surface lithological characterization and formation of hydrostratigraphic units have been produced by analyzing the individual lithological units and depth of different aquifers from the available two lithological borelogs of Muksudpur and three lithological borelogs data of Nagarkanda in the study area. However, among the borelogs maximum depth of the available borelog is 210m. IWM customized software “depth-storage” model is used for producing hydrostratigraphic columnar sections and determining specific yield of the sediment formations. From striplogs distribution, it reveals that a productive aquifer exits below the municipality the alteration of aquitard and aquiclude layers. Produced columnar sections and specific yield of four borelogs indicate that top most clay layer varying at different depth from place to place. A prominent aquifer at Muksudpur Upazila is evidenced within the depth from 170m to 200m or more throughout the area. Specific yield of this aquifer varies from 0.03 to 0.20 indicates that the aquifer consists of fine to medium sand. Hydrostratigraphic sections developed from individual borelogs lithology represent the hydrostratigraphic layers distributions in the Muksudpur municipality and its surrounding area. It reveals that top most layer is aquiclude. Below the aquiclude layer, two composite layers of aquifer are evidenced within different depths and separated by clay layer. A thick aquifer having thickness approximately 80m exists at Lohachura of Muksudpur, which turns into composite aquifer in the other locality in the study municipality. However, a prominent aquifer is evidenced throughout the study area at varying thickness having thickness more or less 30m just below the composite layer at depth from 170m to 200m. From the analysis of storage coefficient and hydrostratigraphic sections, it reveals that the aquifer is confined in nature. 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.

Table 4 Summary of hydrostratigraphic units and their extents in Muksudpur municipality

Hydrostratigraphic Unit	Depth (m)		Average Thickness (m)
	from	to	
1st Aquiclude	0	10	10
1st Aquitard	11	40	30
1st Aquifer	41	120	80
2nd Aquiclude	121	155	34
2nd Aquitard	156	170	15
2nd Aquifer	171	200	30
3rd Aquiclude	201	260	60

5.2. *Modelling and simulation of groundwater system*

For the purpose of GW source identification and resource availability assessment, large numbers of hydrogeological and meteorological data have been collected. For hydrogeological study and GW resource assessment, specific emphasis has been given for the municipality area and its vicinity at least the area of Muksudpur upazilla. It is widely recognized that in GW modelling, a larger study area is usually considered to avoid the boundary influences in model computations. However, GW model setup involves a geometrical description and specification of physical characteristics of the hydrological system of the area under consideration. In this study, the model has been developed using MIKE-SHE mathematical modelling software tool, developed by DHI Water and Environment Pty Ltd. MIKE-SHE is a comprehensive mathematical modelling system that covers the entire land-based hydrological cycle, simulating surface flow, infiltration, flow through the unsaturated zone (UZ), evapotranspiration and GW flow. It is designed to address dynamic exchange of the water between these components. 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 (OL), UZ and saturated zone (SZ) have been used for entire simulation period. However, simulation periods of the calibration, validation and prediction models were different and user specified. However, in this study, the model domain covers an area of about 9,582 sq. km., which includes Meherpur, Kushtia, Chuadanaga, Jhenaidah, Magura, Rajbari, Faridpur and part of Gopalganj, Narail & Jessore districts of Bangladesh. The study area has been discretized into 1 km square grids in the horizontal plan and the model has 9,998 grid cells, where 420 grids are the boundary cells and the rest are computational cells. The grid cells are the basic units to provide all the spatial and temporal data as input and to obtain corresponding data as output. The coupling of SW and GW system involves a number of specifications. The river reaches where the coupling will take place have been defined in the river model. In the present study, all the major rivers and khals within the study area have been coupled with GW system. All forms of river-aquifer exchanges and the flooding conditions have also been defined. The flow exchange between the SZ component and the river component is mainly dependent on head difference between river and aquifer and properties of riverbed material such as leakage coefficient. For river-aquifer dynamic flow exchange, leakage coefficients along with the hydraulic conductivity of the SZ are taken into account for most of the river reaches. The developed model is then calibrated for the period of 1997 to 2003. During calibration phase, overland leakage coefficient, vertical hydraulic conductivity, storage coefficient and river leakage coefficient have been adjusted. In the present model, calibration is done against observed GW level and total 62 monitoring wells have been used for the calibration and validation purposes. In order to increase the reliability of the model, it is verified based on another set of data, which is taken as 2004 to 2007. After successful calibration and validation of the developed model, it is used for GW simulation and resource assessment purposes.

5.3. *Estimation of available groundwater resources*

In this study, GW resource has been estimated based on the well known GW fluctuation technique as well as GW balance study on the basis of long-term simulation. The data analysis suggests that only two geological layers exist within 7m depth. Saturated thicknesses of these two layers have been calculated based on the following considerations:

- Case (i): if thickness of first layer exceeds 6m or 7m depth, entire saturated thickness lies only in first layer.
- Case (ii): if thickness of first layer remains above GW level, entire saturated thickness lies only in second layer.
- Case (iii): if case (i) & case (ii) do not occur, then saturated thickness lies in both first and second layers. To find out the thickness of first layer within the saturated thickness, simply depth of water table is subtracted from the thickness of first layer. Then, part of first layer within the saturated thickness is subtracted from the entire saturated thickness to find out the thickness of second layer within the saturated thickness.

According to GW level fluctuation method, saturated thickness of 1st and 2nd layers are multiplied by the corresponding specific yield values and summed up to find out the depth of available water in a model grid. GW availability in volumes is estimated by multiplying the depth of water availability with the area of the grid (volume of water = area x Δh x S_Y, where Δh is the saturated thickness within 6m and 7m depths). Now, total available GW resource is estimated based on the number of grids lying within the area under consideration. Finally, GW resource availability has been assessed in 2003 at base condition (selected from return period analysis of rainfall) for two different depths (within 6m and 7m) within Muksudpur municipality. The result shows that GW resources for under these two different depths are found as 14.29 million cubic meter (MCM) for 6m depth and 17.71 MCM for 7m depth, respectively. However, the depth of 6m and 7m is used for the unconfined aquifer to calculate the available GW resources within the limit of suction mode pump. However, in order to maintain the long-term sustainability of the underlying aquifer and sustainable GW resources development in and around the study area, the deeper aquifer is found more reasonable for water supply. Keeping this in mind, long-term simulation is executed for the developed GW model and a water balance study for the whole model domain has been performed. The net GW recharge for the deeper aquifer is estimated as net recharge = 0mm (from upper layer) – 13mm (for outflow) + 229mm (for inflow) = 286mm, which mostly comes from the horizontal flow. For this GW recharge amount, corresponding annual aquifer storage volume is estimated by multiplying the aquifer catchment area and found as 7.25 MCM per annum.

5.4. *Groundwater quality analysis*

For GW quality study, a test well was constructed screening the target aquifer so that samples could be collected from the target aquifer. In this regard, it may be mentioned here that the exploratory drilling at Muksudpur was completed and test tube well had been installed. At the same time, GW samples were collected, but water quality results have not been received yet. For this reason, data available from DPHE for a private well at Basatia mouza of Ajmirigang is available and presented in Table 5. Based on the analysis of GW quality data, it is obvious that Arsenic is of higher concentration in this groundwater sample than allowable limit of Bangladesh standard. The GW quality analysis reveals that almost all the parameters have been found within the allowable limit of drinking water standard of Bangladesh. However, little treatment is required for only few parameters crossing the allowable limit. Therefore, GW source can be used as a potential source for urban water supply in Muksudpur municipality.

Table 5 Summary of GW quality test results in Muksudpur municipality

SL	Water Quality Parameters	Unit	Allowable Limit (ECR, 1997)	Water Quality (DPHE Well)
1	Arsenic (As)	ppb	50	281
2	Barium (Ba)	ppb	10	0.139
3	Cadmium (Cd)	ppb	5.0	--
4	Chromium (Cr)	ppb	50	<0.002
5	Aluminium (Al)	mg/L	0.20	0.02
6	Ammonia (NH_3)	mg/L	0.50	--
7	Boron (B)	mg/L	1.0	<0.1
8	Bicarbonate (HCO_3)	mg/L	--	--
9	Calcium (Ca)	mg/L	75.0	94.1
10	Chloride (Cl)	mg/L	150-600	--
11	Cobalt (Co)	mg/L	--	<0.003
12	Copper (Cu)	mg/L	1.0	0.008
13	Fluoride (F)	mg/L	1.0	--
14	Iron (Fe)	mg/L	0.3-1.0	2.47
15	Potassium (K)	mg/L	12.0	5.2
16	Lithium (Li)	mg/L	--	0.006
17	Lead (Pb)	mg/L	0.05	--
18	Magnesium (Mg)	mg/L	35.0	36.0
19	Manganese (Mn)	mg/L	0.10	0.171
20	Nitrate (NO_3)	mg/L	10.0	--
21	Sodium (Na)	mg/L	200	16.4
22	Phosphorus (P)	mg/L	--	0.2
23	Silica (Si)	mg/L	--	20.2
24	Sulphate (SO_4)	mg/L	400	0.6
25	Strontium (Sr)	mg/L	--	0.539
26	Vanadium (V)	mg/L	--	<0.002
27	Zinc (Zn)	mg/L	5.0	0.13

6. Conclusions

In this study, existing SW and GW sources in the Muksudpur municipality have been assessed to identify the potential safe source for sustainable municipal water supply. For the proposed water supply scheme in Muksudpur municipality, the projected water demand is calculated as 4825 m^3/d in the design year 2040. The estimated result indicates that both SW and GW sources have sufficient amount of water resources to meet the estimated demand. At the same time, water quality of these two sources is acceptable for drinking water supply in the municipality. However, little treatment scheme should be planned for few parameters to ensure the high standard. Finally, this study suggests that regular monitoring of the water quality parameters must be ensured for safe and sustainable water supply in the Muksudpur municipality under Gopalganj district of Bangladesh.

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