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SCENARIO-BASED SIMULATION AND DESIGN OF PROPOSED WATER SUPPLY NETWORK IN LOHAGARA MUNICIPALITY, NARAIL, BANGLADESH

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ABSTRACT

In this study, three alternative models of water supply pipe networks (model-1: surface water source with treatment plant, model-2: groundwater source without treatment plant, model-3: groundwater source with treatment plant) in Lohagara municipality of Narail district have been developed and simulated based on the collected data and information. The simulation result of model-1 shows that one high lift pump having capacity of 335.54 m^3/hr and delivery head of 10 m (abstracting water from clear water reservoir) is sufficient to maintain minimum residual pressure of 5 m water column at any point of the distribution network up to the design year in 2040. The model-2 result shows that the daily water demand of 8,053 m^3/d at the end of design year (2040) can be met by only three production wells assuming a safe yield of 102 m^3/hr from each 150mm diameter production well. The analysis also suggests that location of these wells should be evenly distributed within the municipality area. The study also suggests that in case of model-3, location of production wells should be closer enough to the water treatment plant as well as minimum distance should be maintained between the production wells with a view to reduce the cost. Since the pipe network for study area has been modelled for different combinations of surface and groundwater sources with and without treatment plant, it is emphasized that attention should be given in selecting appropriate water source based on socio-economic aspects of the locality, environmental issues, taste of the consumers and cost effectiveness of the system.

Keywords: *ArcGIS, Lohagara municipality, Water distribution network, Water supply, Water treatment plant.*

1. INTRODUCTION

Over the last half-century, there has been an increasing trend of population settlement in urban areas especially in developing countries. It has been predicted by United Nations that about 56% of the people in developing countries will be resided in urban areas (Karim and Mohsin, 2009; UNEP, 2002), which will certainly create severe problems due to increasing water demand by the growing populations. Therefore, supply of adequate safe water in the urban areas is a challenging task for the urban development authorities in the developing countries of the world. In the past, efforts were given only for the establishment of supplementary sources to meet the rising demand without considering the quality aspect. However, the most significant aspect of any water resources planning and management strategy is to ensure adequate supply of water with acceptable quality (Nobi and Das Gupta, 1997). At the same time, the main objective of a well established water supply system should ensure continuous supply of water with adequate pressure (Chambers *et al*., 2004). Every year, high amount of budget is invested around the world for providing or upgrading the piped water supply facilities. Even then, a vast population of the world is without safe piped water facilities. About 85% of the cost of a water supply project is used in the distribution system (Swamee and Sharma, 2008). Therefore, design of water distribution system has attracted many researchers due to its involvement with huge cost. However, water distribution networks serve numerous purposes in addition to the provision of water for human consumption, which often accounts for less than 2% of the total volume supplied (Chambers *et al*., 2004). The purpose of water distribution design is to size and configure a system so that it meets existing and future demands while providing pressures above a minimum level for service (Filion *et al*., 2007; Mays, 2001; Mays and Tung, 1992). The distribution system is one of the vital component of every drinking water utility. Networks are designed to meet peak demands and this creates low-flow conditions in parts of the network, which can contribute to the deterioration of microbial and chemical quality of supplied water (Chambers *et al.,* 2004). Thus, its primary function is to provide the required water quantity and quality at a suitable pressure, and failure to do so is a serious system deficiency (NRC, 2006). Modelling existing and future water demand remains the most challenging task in water distribution system design. To facilitate the process somewhat, geographic information systems (GIS) are increasingly being co-opted to assign water demand to network nodes based on user classifications such as residential, commercial, industrial, institutional, etc (Filion *et al.,* 2007).

In Bangladesh, urban population is also rapidly increasing as a result of natural urban growth and migration from

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rural areas. The current urban population is about 38 million and will be reached to about 74 million by 2035 (BBS, 2005). Such growth of population in urban area will certainly impose a huge burden on urban water supply facilities, which may cause a large number of people to be lived without access to safe water supply in urban area of the country. The declining trend of available water supplies is one of the most important environmental concerns faced by the country at present. Department of Public Health Engineering (DPHE) in cooperation with City Corporation or municipality has installed distribution networks for water supply necessary to deliver water to the urban dwellers in major cities of Bangladesh (Karim and Mohsin, 2009). However, some additional projects of DPHE were also conducted to establish the water distribution networks in many other municipalities of the country. The present study was conducted in Lohagara municipality of Lohagara upazilla under Narail district of Bangladesh, where there was no distribution networks available at present for water supply to the residents of municipality. The main objective of this study is to establish a proposed water supply network in the Lohagara municipality based on the available demand and supply scenarios.

2. MATERIALS AND METHODS

2.1 The Studied Municipality

Lohagara municipality is the only urban area of the Lohagara upazila of Narail district. It consists of nine wards and occupies a total area of 16.13 sq. km. (Figure 1). It was established on 2000 and presently it is classified as a 'C' category municipality. Its population has been increasing since its inception. The relative importance of the town has ever been growing as a regional centre of trade and commerce. The water supply system in Lohagara municipality mainly depends on groundwater as the source of water supply. The municipality is divided into 9 wards (Figure 1), which has no existing pipe networks for water supply purpose at present. It is situated on the bank of the Upper Nabaganga River in the south west region of Bangladesh.

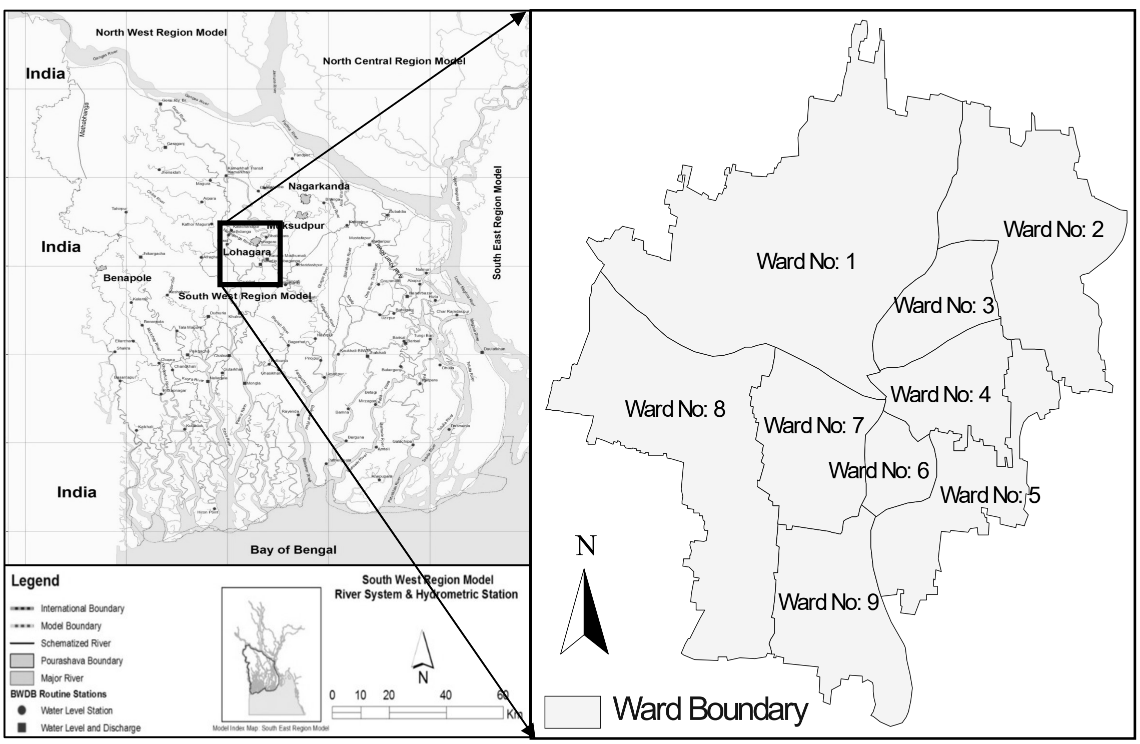

Figure 1: The study area (Lohagara Municipality) in Lohagara Upazilla under Narail district of Bangladesh

2.2 Data Collection

Study of water distribution network modelling requires input data from many sources. Much of this data cannot be measured directly and often it is known precisely (Lansey, 2012). The data and information includes population projection, land use plan, assessment of water sources potentials and topographic information etc. Development and use of water distribution models comprises of many activities and processes. It widely recognized that if the input uncertainty is very high, a model is inadequately calibrated and in that case additional field data is needed to reduce the input uncertainty (Lansey, 2012). Therefore, extensive surveys were conducted to collect as much data as possible in the field. However, input imprecision is propagated to uncertain model predictions. However, some of the data such as present water consumption and present population cannot be measured directly and it is rarely known precisely. In such cases, several established techniques are employed for estimating and quantifying the data and information, which are not directly available.

2.3 Population Projection

For population projection, the geometric progression method is the most widely used method which is also known as empirical method. Population projection on the basis of 2.78 growth rate (Figure 4) is assumed natural increase rate with allowances for internal migration. As the rate of natural increase is expected to continue to be reduced and therefore, reduce population growth rates are considered for the projection periods and is presented in Table 1. From the known population and dwellings of at least two last censuses, growth rate can be estimated by using the Equation (1) as:

$$P_f = P_P\left(1+\frac{r}{100}\right)^n \quad (1)$$

Where,
P_f = Future population or dwellings
P_P = Present population or dwellings
r = Growth rate of population or dwellings and
n = Design period.

Table 1: Estimated projected population in all wards of Lohagara Municipality.

Name of Locality	Projected Population							
	2001	2010	2015	2020	2025	2030	2035	2040
Municipality	23,028	29,347	33,537	38,277	44,626	50,807	59,342	67,398
Ward No-01	3,617	4,559	5,220	5,987	6,871	7,872	9,128	10,504
Ward No-02	2,215	2,781	3,173	3,615	4,119	4,656	5,263	5,820
Ward No-03	2,344	2,965	3,431	3,939	4,531	5,176	5,904	6,654
Ward No-04	2,863	3,430	3,821	4,252	4,732	5,260	5,902	6,554
Ward No-05	2,451	2,948	3,313	3,736	4,222	4,740	5,377	6,038
Ward No-06	1,019	1,228	1,373	1,533	1,714	1,913	2,134	2,368
Ward No-07	3,035	3,632	4,042	4,488	4,988	5,519	6,163	6,837
Ward No-08	2,537	3,337	3,931	4,605	5,406	6,297	7,324	8,408
Ward No-09	3,416	4,465	5,234	6,123	7,171	8,381	9,896	11,661
Extension Area	-	-	-	-	872	993	2,250	2,556

According to GIS based Municipality map, the area is estimated as 16.16 sq. km. and the population is 27,132. Comparing all the stated population figures with the predicted ones for the year 2010 which is 29,347 seems to be on the right track and considered acceptable. Error of the report in case of feasibility level study should be around ±15% and in case of detail design, it is ±5%. This standard is being applied in many of the donor aided water supply projects of World Bank (WB) and Asian Development Bank (ADB) in Bangladesh. To arrive at this target, at least ward wise assessment of population growth rate is necessary for applying in population projection. In Lohagara Municipality, ward wise population for the year 2001 is available as this Municipality is created after 1991 census. In absence of the previous two census (1981 and 1991) population, assessment of population growth rate is quite impossible. Hence, the present study picked up the population figures of 1991 and 1981 from the census reports of 1991 and 1981 for the existing mouzas /localities of the Municipality. Area and population play an important role for the assessment of population growth rate. To figure out the baseline (2001) growth rate in each ward (BBS, 2005), same localities of census 2001, 1991 and 1981 have been sorted out and placed in parallel to the wards of the Municipality. Unfortunately, some of the localities could not be traced out probably for locality name change or the split of locality into more parts. However, ward wise growth rates have been calculated on the basis of the same area and same locality. Thus, a growth rate model of the Lohagara Municipality has been developed and is presented in Figure 2 and Figure 3, respectively.

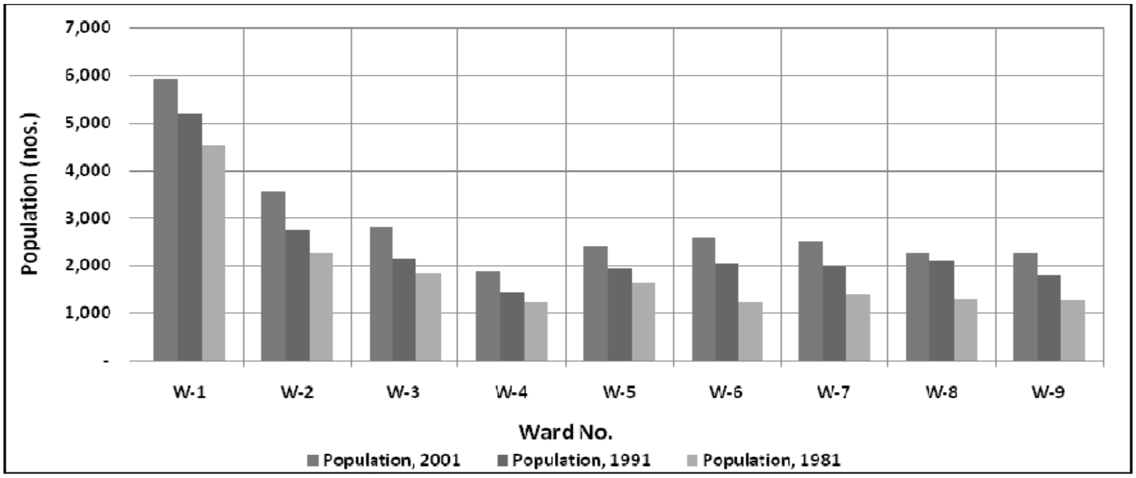

Figure 2: Ward-wise adjusted population for 1981, 1991, 2001 census in Lohagara Municipality

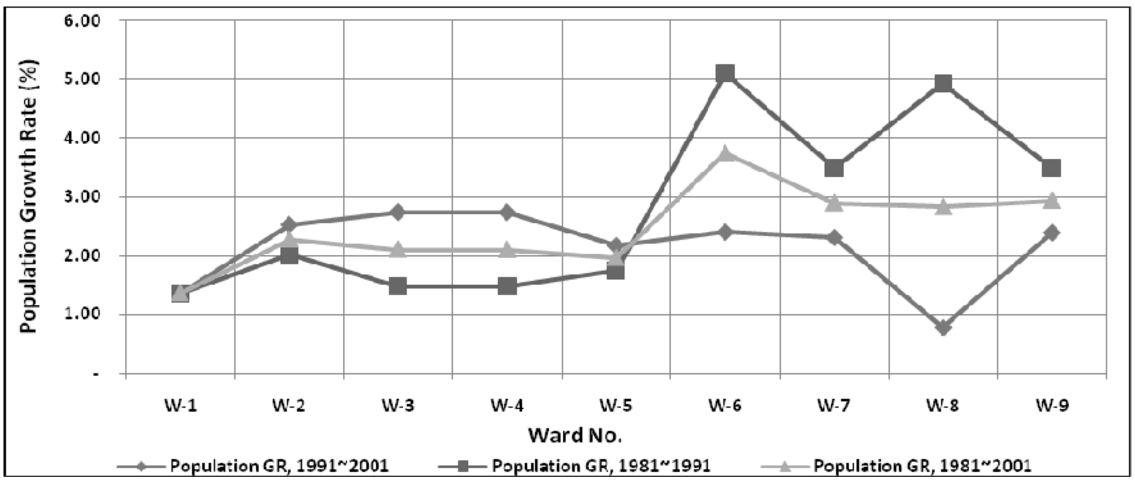

Figure 3: Ward wise population growth rate in Lohagara Municipality

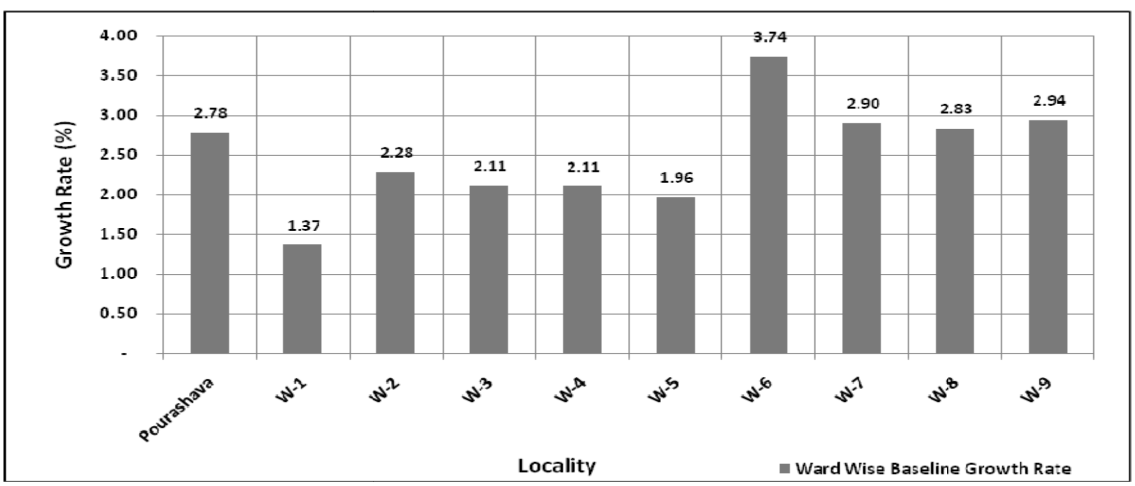

Figure 4: Wardwise baseline growth rate based on 2001 census in Lohagara Municipality

It reveals from the analysis that the growth rate varies significantly within the municipality area and the urban area, where the parenthesis indicate the negative growth rate. There is also found extremely high growth rate in some of the wards. These occur mainly due to frequent changes of Municipality area, inclusion of new mouzas in different wards and inter change of mouzas within the wards. According to the census reports, the average population growth rate during the periods of, 1991-2001, 1981-1991 and 1981-2001 are 2.06, 2.48 and 2.27, respectively whereas ward wise growth rate for the selected localities are in very high side. But growth rate calculated for 2.78 from census report to be acceptable for base line growth rate. There is a general consensus that the population growth rate 2.78 is expected to continue to reduce influencing the household size and households as well. The achievement of such low natural increase rates is attributed to the success of Family Planning Programs throughout the country. This is thought to be conservative due to the probability that higher education levels are associated with a greater awareness for the need of family planning. It has also been suggested that there is still significant scope for ongoing family planning impact. On the basis of the normal growth rate, highest growth of the wards and past experience, the baseline (2001) growth rates listed in Figure 4 has been assumed as applied in projecting the future growth rates up to the design year (2040).

2.4 Estimating Water Consumption and Demand

Assessment of domestic water consumption is not possible where there is no piped water supply as the consumers uses their daily water requirement from both groundwater (GW) and surface water (SW) sources even sometimes from rainwater source. However, residential water demand is one of the most difficult parameters to determine while modelling the drinking water distribution networks (Alcocer-Yamanaka *et al.,* 2012). Quantifying use of SW is just a guess and network designer judgement is predominant here. Domestic water consumption has been proposed on the basis of the published literatures on water supply and water consumption analysis. Estimated domestic water demand and consumption are presented in Figure 5. Water demand up to the end of design year (2040) has been assessed considering intended population coverage by piped water supply system, consumers per connection for different types of service connections, population served through each types of service connections, non-domestic demand including the fire demand, water losses and backwash water (in case of water treatment plant). In order to ensure better life standard in future based on all these factors and previous published reports of DPHE, water demand and consumption has been increased gradually with the increase of population.

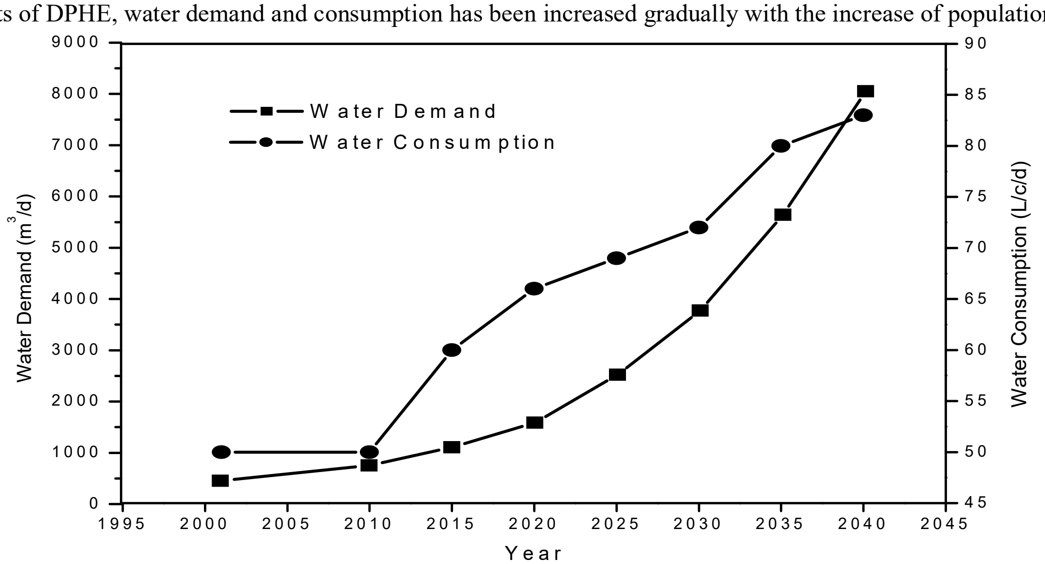

Figure 5: Estimated average domestic water demand and consumption in Lohagara Municipality.

2.5 Assessment of Water Source Potentials

The flows in the Upper Nabaganga River can be used as a sustainable surface water (SW) source for a water treatment plant (WTP) for surface water, which can supply drinking water to the consumers of the municipality. Lohagara municipality intake point is located conveniently on Upper Nabaganga River, which is a schematized river of the South West Region Model (SWRM) developed earlier by Institute of Water Modelling (IWM). The Upper Nabaganga is basically a spill channel from the Padma River, which drains into the Gorai River basin. It has significant discharge, which reduces during the dry season. However, flows in Upper Nabaganga River were reported to be continuous all throughout the year. The river has linkages with the Ganges through other spill channel but carries lesser discharge. Considering the requirement for a WTP for surface water, the water demand of the municipality is estimated as 0.1001 m^3/s (100.1 L/s) based on the dependable flow analysis using flow duration curve of the Nabaganga River for the period of 1986 to 2009. It is obvious from the result that the surface water is sufficient to satisfy the water demand for WTP. The municipality is characterised by a prominent aquifer at varying thickness of more or less 36 m below the aquiclude at 200 m to 235 m. The estimate on the design year 2003 shows that the upper aquifer is semi-confined and lower aquifer is confined in nature. Based on the water balance studies, it can be concluded that the groundwater (GW) recharge is about 390 mm for the deeper aquifer in 2003, for which the corresponding annual aquifer storage volume is estimated as 7.25 Mm^3. It is also estimated that GW resources in the shallow aquifers of Lohagara municipality at May 01, 2003 for 6 m and 7 m depths are

7.48 Mm^3 and 10 Mm^3, respectively and at November 01, 2003, it is estimated as 11.29 Mm^3 and 13.81 Mm^3 for 6 m and 7 m depths, respectively.

Table 2: Adopted design criteria of water distribution networks in study municipality

Description of Design Parameters	Parameter Values for Simulating Water Distribution Networks							
	2001	2010	2015	2020	2025	2030	2035	2040
(a) Design Period								
Design period (year)	30 from baseline year 2001							
(b) Population Coverage (%)								
Population coverage, % of total population of Municipality	30.00	35.00	40.00	45.00	55.00	65.00	75.00	85.00
Population coverage by individual service connections, % of total population coverage	94.00	94.50	95.00	95.50	96.00	96.50	97.00	97.50
Population coverage by stand post, % of total population coverage	6.00	5.50	5.00	4.50	4.00	3.50	3.00	2.50
(c) Population served by each type of service connections (#/connection)								
Multi tap (people per tap)	9.63	9.84	9.96	10.07	10.19	10.31	10.44	10.56
Single tap (people per tap)	4.82	4.92	4.98	5.04	5.10	5.16	5.22	5.28
Shared tap (people per tap)	14.45	14.76	14.93	15.11	15.29	15.47	15.65	15.84
Street Hydrant (people per tap)	96.32	98.39	99.56	100.74	101.93	103.14	104.36	105.60
(d) Water Demand								
(i) Domestic Demand								
Multi tap (L/c/d)	70	75	80	85	90	95	100	105
Single tap (L/c/d)	40	45	50	55	60	65	70	75
Shared tap (L/c/d)	30	35	40	45	50	55	60	65
Street Hydrant (l/c/d)	15	17	19	21	23	25	27	29
(ii) Non-Domestic Demand (%)								
Total non domestic demand (NDD) (% of total domestic demand)	5.000	6.55	7.92	9.39	10.96	12.64	14.45	16.41
Peak day demand (% of average daily demand)	10.00	9.950	9.900	9.850	9.800	9.750	9.700	9.650
(iii) Unaccounted Water including fire demand								
Water Losses (% of domestic demand + non domestic demand)	10.00	12.36	14.15	16.09	18.19	20.50	23.04	25.86
(iv) Backwash Water								
Water requirement for backwashing of treatment units (% of TDD)	5.00	5.39	5.71	6.04	6.38	6.72	7.06	7.42
(e) Production & Treatment Hours								
Supply (hour)	0.00	0.00	8.00	11.00	14.00	17.00	20.00	23.00
Production (hour)	0.00	0.00	8.50	11.50	14.50	17.50	20.50	23.50
Treatment (hour)	0.00	0.00	8.50	11.50	14.50	17.50	20.50	23.50
(f) Storage								
Ground tank,% of TD	15%							
Overhead tank,% of TD	15%							
(g) Distribution Network								
Peak factor for 24 hours supply	2.5							
Peak factor for 12 hours supply	1.25							
Peak factor for 8 hours supply	0.83							
Maximum Pressure (m)	15.0							
Minimum Pressure (m)	5.0							
Minimum diameter (mm)	100							

2.6 Adopted Design Criteria for Proposed Water Supply Network

Adopted design criteria have been assumed on the basis of the adopted design criteria of previous DPHE projects, field surveys, available literatures on water supply system and past experience and judgement. The adopted design criteria followed in the present study is presented in Table 2.

2.7 Simulating Proposed Water Supply Network Model

Hydraulic simulation models of water distribution networks are normally used for operational investigations and network design purposes. However, their full potential is often never realised because, in the majority of cases, they have been calibrated with data collected manually from the field during a single historic time period and, as such, reflect the network operational conditions that were prevalent at that time. In order to use a hydraulic simulation model to assist proactive distribution network design and management, its element asset information must be up to date and it should be able to access current network information to drive simulations. However, such advance has been restricted by the high cost of collecting and transferring the necessary field measurements. A conventional simulation model for distribution networks is comprised of static asset information including pipe lengths, diameters, connectivity, and network topography etc., and information about dynamic parameters, such as the distribution of demand, and elements such as pumps, reservoirs and valves. Most contemporary modelling packages in current use utilise models that include every main down to the level of, but not including, customer service pipes. Standard daily time-varying demand relationships are estimated for different user types, and these are summed and allocated at pipe junctions (nodes) according to the distribution of users. The models are normally used to simulate flows and pressures over a fixed (normalised data from a specific date) 24 h period which provides enough information to be suitable for purpose (Machell *et al.,* 2010).

2.7.1 Nodal Demand Assessment

For nodal demand assessment, the area under each node, population density, assessment of service connections of each type and flow through each type of connection are needed. Linking all these spatial and non-spatial data has been completed by using the analytical ability of ArcGIS toolkit. Nodal demand calculation has been done by a spreadsheet program developed in MS Excel.

2.7.2 Digitization of Network Modelling Data

There are three types of data and information, which are essential for assembling a water distribution model.

(i) Network Data: Network data describes all physical components of the water distribution system and defines the interconnected patterns of those elements. Networks are made up of nodes and links: nodes represent water system features at specific locations and links define relationships between nodes. Network data can include traditional data, which is mainly composed of two primary types – pipe and node data. Network geometry data is now generally available in the Geographical Information System (GIS) format.

- Intake and WTP for SW Source: For modelling with SW source, an intake has been digitized along with a WTP beside the Nabaganga River. Treated water from the clear water storage reservoir with a rate of 97.28 lit/s with a delivery head of 10 m is to be injected to the distribution system. Ground elevation at pumping location is +5 m.PWD (public works datum in Bangladesh) and hydraulic grade line level will be maintained as +10 m.PWD.
- Pumping stations: Pumping stations are needed for modelling with GW source. Based on the aquifer characteristics, required flow to meet the existing demand and total head needed, pump has to be selected carefully.
- WTP for GW Source: In case of groundwater quality is not acceptable according to the WHO/Bangladesh water quality standard (WHO, 2006; ECR, 1997) WTP is needed to be constructed. Pumps will be used as the sources for WTP, which should be spaced about more than 1 km. apart so that no overlapping of influence zone occurs.

(ii) Water **Demand Data:** Water demand data describes two basic components of overall demand – metered or non-metered consumption and water losses from the distribution systems. Total daily water demand data is assigned to nodes in the modelled network. Modelling demand (consumption rates) and its distribution throughout the network is one of the key elements of a water distribution model. As such, the spatial distribution of demand and its variation over time must be carefully modelled.

(iii) Operational Data: Operational data describes actual operational system characteristics at a given time. Operational data is required to model water levels in reservoirs and status of pump stations. Operational data could be generally obtained from water utilities operational staff.

Figure 6: Simulated velocity, flow and headloss in proposed distribution network of Lohagara Municipality

2.7.3 Model Building and Data Entry

Water distribution network model is assembled by applying two basic data entry procedures. At first, data is manually created by typing it into the model and then data has been transferred between various files by simply importing the data from one file to another, which also requires some additional manual editing techniques.

2.7.4 Model Calibration and Validation

Calibration is the process of adjusting model input data so that simulated hydraulics and water quality results adequately reflect observed field data. Calibration is an extremely important part of the modelling process of distribution systems. The process of calibration can be difficult, time-consuming, and costly. An accurate representation of the system and components is a must adequately to perform the calibration process. Two of the major sources of error in simulation analysis for hydraulics are demands (loading distribution) and pipe-carrying capacity. The importance of each of these error sources will depend on the network simulation. Use the measured values in a simulation model and adjust pipe friction factors followed by a simulation. Continue this process until friction factors are selected that provide simulated pressures and flows that reflect the measured data. Other adjustments that may be necessary are adjusting pressure-regulating valves, redistributing demands, adjusting pipe diameters, and adjusting pump lifts. Calibration can also be performed by comparing measured water surface elevations in tanks with simulated elevations in tanks. It is adjustment of model parameters so that predicted results adequately reflect observed field data (Mays, 2001).

Water Supply model calibration process involves adjustments of the following primary network model parameters: pipe roughness coefficients, spatial distribution of nodal demand, altering pump operating characteristics, pipe diameter and some other model attributes until the model results sufficiently satisfies the objectives. Model Validation is the process of independent comparison of model and field results to verify the adequacy of the model representation (Mays, 2001). Once a model is calibrated to match the project objectives, to gain full confidence in the model, model is validated using additional sets of data under different operational conditions. In performing validation, system demands, initial conditions and operational regimes need to be adjusted to match the conditions at the time the additional field data set was collected. The proposed water distribution networks and the simulated hydraulic parameters of those networks in Lohagara Municipality is presented in Figure 6.

3. RESULTS AND DISCUSSION

3.1 Selection of Water Sources for Model Simulation

Nabaganga River is flowing through Lohagara Municipality of Lohagara upazilla under Narail district of Bangladesh. As both SW and GW sources are available, three separate alternative models of water distribution pipe network for Lohagara Municipality have been developed.

Scenario-1: the first model is built for SW source with water treatment plant
Scenario-2: the second model is developed for GW source without water treatment plant and
Scenario-3: the third model is constructed by considering GW source with water treatment plant

For both SW and GW sources with or without WTP, one high lift pump (abstracting water from clear water reservoir) of capacity 335.54 m^3/hr at one bar (10 m) delivery head is sufficient to maintain minimum residual pressure of 5 m water column at any point of the distribution system up to year 2040. For ground water source, the pipe network models have been built on the basis of the secondary data and the past experience in the field. Safe yield (abstraction) from one 150 mm diameter production well is 102 m^3/hr has been assumed and the locations of these well are evenly distributed within the Lohagara Municipality area. On the basis of the above assumption, total of 3 numbers production wells will be required to meet the daily water demand of 8,053 m^3/d at the end of design period on 2040. It is estimated that selecting a pump of 102 m^3/hr at one bar (10 m) delivery head, will be sufficient to maintain minimum residual pressure of 5 m water column at any point of the distribution system up to the design year (2040).

3.2 Scenario-1: Network Design for Surface Water Supply Option with WTP

In case of SW source for water supply, treatment of raw water is a must. Pipe network model for SW source starts from the clear water storage reservoir situated on the ground of the SW treatment plant. High lift pumping station will be needed to inject required quantity of treated water with certain discharge head to achieve the targeted minimum residual pressure (5 m water column) at any point of the distribution pipe network. Output of the model is presented in the form of junction data, pipe data and high lift pump data. High lift pump situated on the ground surface just after the clear water storage tank of the water treatment plant abstracting required quantity of treated water from the clear water storage tank will inject in the distribution system with certain discharge head to maintain the minimum residual head (5 m water column) at any point of the pipe network. The pipe network model is simulated by pipe network modeller. After each run of the pipe network model, the network is calibrated with pump discharge head and suitable pipe diameters to satisfy design criteria. The proposed pipe length for water supply in Lohagara Municipality is presented in Table 3.

3.3 Scenario-2: Network Design for Groundwater Supply Option without WTP

A GW model generally consists of reservoirs, pumps, junctions and pipe network. In absence of GW source assessment result, model has been simulated by reservoirs only instead of pumps and reservoir combination as source. Like the SW supply model, similar representation approach has been followed in output for junction data and pipe data. Reservoir data is an additional output for GW supply model. The pipe network model is run by pipe network modeller. After the simulation run, the network is calibrated with pump discharge head and suitable pipe diameters to satisfy design criteria. The proposed pipe length is presented in Table 4.

Table 3: Ward wise designed pipe length and size for SW supply model with WTP

Ward No.	Designed Pipe Length (km)						Grand Total (km)
	100mm Dia	150mm Dia	200mm Dia	250mm Dia	300mm Dia	350mm Dia	
Ward No: 01	11.96	5.34	2.48	0.00	0.23	1.79	21.81
Ward No: 02	12.15	0.40	0.00	0.00	0.00	0.00	12.55
Ward No: 03	7.27	1.47	1.10	0.00	0.00	0.09	9.93
Ward No: 04	4.16	2.52	0.84	0.00	0.03	0.10	7.63
Ward No: 05	6.47	0.62	0.10	0.00	0.00	0.00	7.20
Ward No: 06	3.10	0.41	0.68	0.81	0.01	0.00	5.01
Ward No: 07	11.79	0.56	0.84	0.00	0.10	0.00	13.29
Ward No: 08	16.42	1.36	0.00	0.00	0.00	0.00	17.78
Ward No: 09	6.58	1.77	0.65	0.10	0.00	0.00	9.10
Total (km)	79.90	14.44	6.69	0.91	0.37	1.98	104.30

Table 4: Ward wise designed pipe length and size for GW supply option without WTP

Ward No.	Designed Pipe Length (km)				Grand Total (km)
	100mm Dia	150mm Dia	200mm Dia	250mm Dia	
Ward No: 01	15.71	3.00	3.05	0.00	21.77
Ward No: 02	10.99	1.15	0.19	0.33	12.66
Ward No: 03	8.86	0.83	0.24	0.00	9.93
Ward No: 04	4.77	1.25	1.16	0.46	7.63
Ward No: 05	6.45	0.48	0.26	0.00	7.20
Ward No: 06	3.93	0.67	0.41	0.00	5.01
Ward No: 07	11.17	2.02	0.10	0.00	13.29
Ward No: 08	17.26	0.51	0.00	0.00	17.78
Ward No: 09	7.38	0.40	1.18	0.27	9.23
Total (km)	86.53	10.32	6.59	1.06	104.51

3.4 Scenario-3: Network Design for Groundwater Supply Option with WTP

In case of GW source, if the GW quality is not suitable for direct supply to the consumers, WTP is required to bring the water quality according to the WHO/Bangladesh water quality standard. As the source selection not finalized during the model built up, another model has been simulated for GW source with WTP. Pipe network model for GW source with treatment, starts from the clear water storage reservoir situated on the ground of the GW treatment plant. High lift pumping station will be needed to inject required quantity of treated water with certain discharge head to achieve the minimum desired residual pressure (5 m water column) at any point of the distribution pipe network. Output of the model is presented in the form of junction data, pipe data and high lift pump data. High lift pump situated on the ground surface just after the clear water storage tank of the water treatment plant abstracting required quantity of treated water from the clear water storage tank will inject in the distribution system with certain discharge head to maintain the minimum residual head (5 m water column) at any points of the pipe network. The pipe network model is simulated by pipe network modeller and after each model runs, the network is calibrated with pump discharge head and suitable pipe diameters to satisfy design criteria. The proposed pipe length is shown in Table 5.

Table 5: Ward wise designed pipe length and size for GW supply option with WTP

Ward No.	Designed Pipe Length (km)						Grand Total (km)
	100mm Dia	150mm Dia	200mm Dia	250mm Dia	300mm Dia	350mm Dia	
Ward no: 01	19.48	1.98	0.21	0.00	0.00	0.00	21.81
Ward No: 02	10.99	1.15	0.19	0.21	0.00	0.00	12.55
Ward No: 03	8.31	1.07	0.55	0.00	0.00	0.00	9.93
Ward No: 04	3.92	0.80	0.67	0.92	0.79	0.54	7.63
Ward No: 05	6.45	0.48	0.26	0.00	0.00	0.00	7.20
Ward No: 06	3.23	0.33	0.37	1.01	0.07	0.00	5.01
Ward No: 07	10.16	3.03	0.11	0.00	0.00	0.00	13.29
Ward No: 08	16.23	1.55	0.00	0.00	0.00	0.00	17.78
Ward No: 09	7.38	0.40	1.07	0.24	0.00	0.00	9.10
Total (km)	86.15	10.80	3.44	2.38	0.86	0.54	104.30

4. CONCLUSIONS

In the present study, three alternative models of water supply distribution networks have been developed for proposed water supply purposes in Lohagara municipality of Narail district based on the collected data and information. The first model refers to the combination of SW source with WTP, second model is relevant to the GW source without WTP, and third model is build by using GW source with WTP. Based on the simulations and results obtained, a water distribution network is proposed for the Municipality area. Since the pipe network for the study area has been modelled for different combinations of SW and GW sources with or without WTP, it is emphasized that proper attention should be given in selecting appropriate water sources based on the socio-economic aspects of the locality, environmental issues, taste of the consumers and cost effectiveness of the system. The simulation result of the first model shows that one high lift pump having capacity of 335.54 m^3/hr and delivery head of 10 m (abstracting water from clear water reservoir) is sufficient to maintain minimum residual pressure of 5 m water column at any point of the distribution network up to the end of design period 2040. The simulation result obtained by the second model reveals that the daily water demand of 8,053 m^3/d at the end of design year can be met by only three production wells assuming a safe yield of 102 m^3/hr from each 150 mm diameter production well. The analysis also suggests that location of these wells should be evenly distributed within the municipality area. According to the third model simulation of water distribution networks, production wells should be located in such a way that they are closer enough to the WTP as well as minimum distance should be maintained between the production wells with a view to reduce the cost of water withdrawal and/or water production. As depicted in the design criteria section, minimum water pressure at the consumers end has been ensured not less than 5 m water column. This indicates that the owner of the high rise buildings need underground water reservoirs. However, for one storey buildings, no underground reservoir is necessary. From the analysis of the network, the hydraulic properties of each node and pipe are found from the software used for the modelling task. The detailed results of these node and pipes with selected hydraulic properties such as demand, hydraulic grade and pressure as well as pipe hydraulic properties such as diameter, velocity, head loss gradient and flow are provided for assisting in their calculation from time to time in future.

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REFERENCES

Alcocer-Yamanaka, V.H., Tzatchkov, V.G. and Arreguin-Cortes, F.I.: Modeling of Drinking Water Distribution Networks Using Stochastic Demand, Water Resources Management, Vol. 26(7), 1779-1792, 2012.

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

Chambers, K., Creasey, J. and Forbes, L.: Design and Operation of Distribution Networks, In Safe Piped Water: Managing Microbial Water Quality in Piped Distribution Systems by Richard Ainsworth (ed.), IWA Publishing, London, UK, 2004.

ECR (Environment Conservation Rules of Bangladesh): Bangladesh Gazette, Environmental Conservation Rules-1997, Ministry of Environment and Forest (MoEF), Government of Bangladesh, 1997.

Filion, Y., Adams, B. and Karney, B.: Cross Correlation of Demands in Water Distribution Network Design, Journal of Water Resources Planning and Management, Vol. 133(2), 137-144, 2007.

Karim, M.R. and Mohsin, G.M.: Assessment of Urban Water Supply Situation: A Case Study in Khulna City Corporation Area, Proceedings of the 2nd International Conference on Water and Flood Management (ICWFM-2009), Dhaka, Bangladesh, Vol. 1, 235-242, 2009.

Lansey, K.: Uncertainty in Water Distribution Network Modeling (Accessed on: 22 January, 2012) Available at: www.ucowr.org/updates/pdf/V103_A4.pdf

Machell, J., Mounce, S.R. and Boxall, J.B.: Online Modelling of Water Distribution Systems: a UK Case Study, Drinking Water Engineering and Science, Vol. 3, 21-27, 2010.

Mays, L.W.: Water Resources Engineering, John Wiley & Sons, Inc., New York, USA, 2001.

Mays, L.W. and Tung, Y.K.: Hydrosystems Engineering and Management, McGraw Hill Inc., New York, USA, 1992.

Nobi, N. and Das Gupta, A.: Simulation of Regional Flow and Salinity Intrusion in an Integrated Stream-Aquifer System in Coastal Region: Southwest Region of Bangladesh, Ground Water, Vol. 35(5), 786-796, 1997.

NRC (National Research Council of the National Academics): Drinking Water Distribution Systems: Assessing and Reducing Risks. The National Academic Press (NAP), Washington, D.C., USA, 2006.

Swamee, P.K. and Sharma, A.K.: Design of Water Supply Pipe Networks. Wiley-Interscience, John Wiley & Sons, Inc., New Jersey, 2008.

UNEP (United Nations Environment Program): Vital Water Graphics, An Overview of the State of the World's Fresh and Marine Waters, United Nations Environment Program, 2002.

WHO (World Health Organization): Guidelines for Drinking Water Quality. World Health Organization, Geneva, Switzerland, 2006.