Efficiency Study of a Pilot Water Distribution System Using EPANET and ArcGIS10

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ABSTRACT:
Hydraulic integrity problem is mostly associated with the water distribution system (WDS) of developing countries. The problem of integrity of network is further exemplified by deteriorated condition of network that leads to high leakage rates.
In the present study, the performance of the WDS in a pilot study area of Nagpur city (India) is evaluated using EPANET software. Both continuous as well as intermittent water supply simulations are performed. ArcGIS10 is used to generate the maps of water supply network, node network, and elevation map. Remote sensing image is used to generate the population data. The HydroGen extension to ArcView which is a series of Avenue scripts is used to create hydraulic model data input files for EPANET. Model simulation results obtained using EPANET for the both supply modes identify critical areas with respect to pressure drop at various nodes. The suggestions made for controlling leakage and maintaining hydraulic integrity of the system are useful for the municipal authority for implementing 24×7 water supply scheme.

1. INTRODUCTION

Water has always been acknowledged as a primary good and an indispensable natural resource. As the standard of living increases; so does the need for consumption of water for various anthropogenic activities. In general, more people use more water. Even if the amount used individually is reduced by education, the implementation of conservation practices or technological improvements in water distribution systems (WDS) are must.

A typical WDS consists of network of pipes, nodes linking the pipes, storage tanks, reservoirs, pumps, additional appurtenances like valves (Rossman, 2000; Walski, 2003). A common problem in developing countries is that WDS are designed for continuous supply mode, but are operated in intermittent supply mode which leads to hydraulic integrity problem (CPHEEO, 1999). In intermittent supply, the duration of water supply is variable; it may be 1-2 hour per day or 3-4 hour per day (Peter, 2006). This water supply mode is very common in many cities in India (Jethoo, 2011). It is important to note that the hydraulics of the intermittent water supply is different than that of continuous water supply. A continuous water supply is based on “Demand driven analysis”, while the intermittent water supply is “Pressure/head dependent”. The softwares including EPANET developed for network analysis are based on the “Demand-driven” assumption, wherein, the nodal demands are assigned fixed values and the problem is to find pipe flows and nodal pressures that are hydraulically consistent with these demands, whereas in intermittent water supply, the demand is a function of pressure. Serious risk to public health, customer inconvenience and problems of water quantity and quality are the major drawbacks of an intermittent water supply system.

Ineffective water supply and demand management, operational inadequacies unduly weaken the physical infrastructure in many urban areas. As the pressure to fill the gap in water and sanitation access grows, many people are making a case that all the nations of the world, particularly the poor ones, should go beyond just planning for basic water access and aim for 24x7 water supply. Thus the municipal water sector in recent years has been subjected to a process of constant changes. Today there is a pronounced focus on how to make the existing WDS more efficient in urban sectors. Under Jawaharlal Nehru National Urban Renewal Mission (JNNURM) which is a massive city-modernization scheme launched by the Government of India under the Ministry of Urban Development, the intermittent water supply mode of Nagpur city is being upgraded to 24×7 water supply mode (*Ministry of Urban Development*). Thus, there is an immediate need to evaluate the performance of the existing WDS to address the current and future issues related to its hydraulic efficiency. In this context, the paper presents evaluation of performance of the pilot WDS of Nagpur city using EPANET software.

2. METHODOLOGY

The performance of a WDS depends on a number of criteria such as its physical structure, operational parameter and other environmental factors. In the present study, WDS for a pilot study area has been analyzed using hydraulic simulation model, EPANET in conjunction with geographic information systems (GIS) for both intermittent and continuous supply. The performance studies outline the criticality of WDS with greater precision.

The operation and maintenance data required for the study is obtained from the Nagpur Municipal Corporation (NMC), which looks after the WDS of pilot area. Periodical site visits as well as discussion with the NMC helped in finding the pipe condition, pressure and leakage information. The leakage in the system is quantified to 4.6 lps. In situ measurements of temperature, pH, flow rate and pressure are conducted for validation of model results. This information helped in network building as well simulation studies.

2.1. Study Area

Untkhana, the pilot study area of the orange city, Nagpur is under Dhantoli water supply zone. The study area of 0.4382 sq km is bounded by Latitude 21^{o}07'30"N to 21^{o}08'15"N and Longitude 79^{o}05'30"E to 79^{o}06'15"E as shown in Fig. 1. Consumers in the study area depend on the public water supply. Water is supplied from the GSR located at Governor House. The water distribution network is operating since 1980. The present water supply hour is 6:00 to 7:30AM per day. Other information about the study area is given in the Table 1.

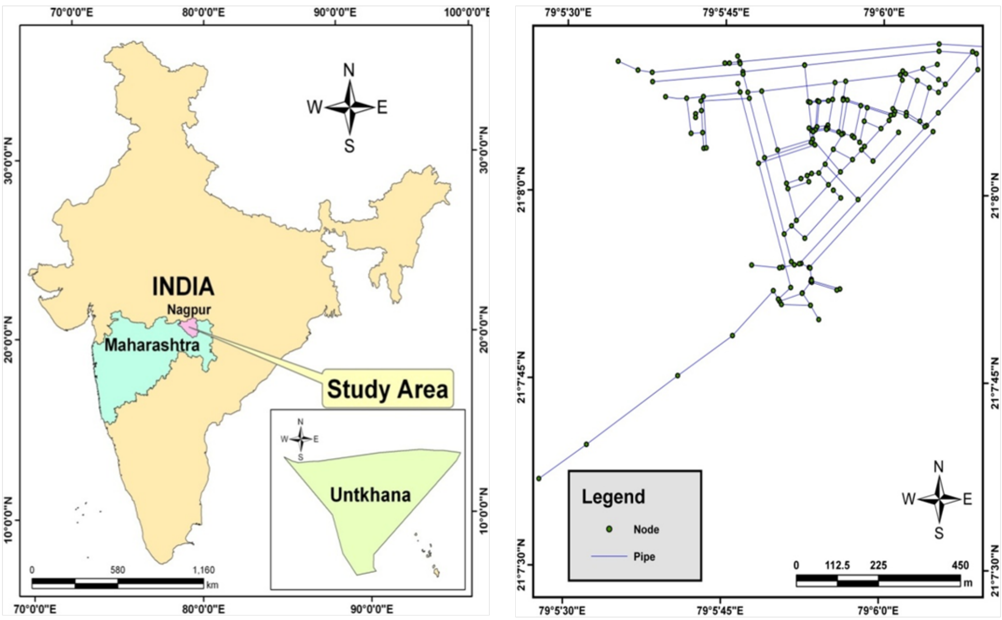

Figure 1. Pilot study area, Untkahana

Table 1. Study area details

Study Area	Untkhana
Population	4630

No. of Pipes	172
Pipe Material	Mild Steel (MS), Cast Iron (CI), Galvanized Iron (GI), Ductile Iron (DI).
Diameter	75 to 700 mm
Year of Installation	1980 to 2011
No. of Nodes	146
No. of ESR/GSR (Source)	1
Roughness	75 to 140

2.2. GIS Analysis

Preliminary GIS analysis including pilot study area WDS map digitization, geo-referencing, DEM analysis for elevation map generation and attribute table generation are performed for data preparation for EPANET.

The HydroGen extension to ArcView which is a series of Avenue scripts that allow the user to create hydraulic model data files with the associated map file in an EPANET “inp” format file was used to build the network model (HydroGen, 2000). The three shape files used to create model data files were a pipe map (stores pipe data), a route map (provides demand information) and an elevation polygon map (provides elevation data for nodes). Overlaying analysis is performed to identify the areas under low pressure. This is a cost effective as it will provide decision support in operation and maintenance of the system.

2.3. EPANET

The free software developed by USEPA, EPANET was used for the simulation of both intermittent and continuous supply mode with suitable assumptions (Rossman, 2000). The Hazen-Williams formula is the most commonly used headloss formula for the hydraulic head lost by water flowing in a pipe due to friction with the pipe walls, is being used for the present study (Eq. 1). The .net file was imported and ESR was defined in the network. Baseline data with respect to pipe age information was collected from the NMC. Considering the pipe age, suitable roughness for worst case scenario was adopted from literature (Walski, 2003). Leakage value of 4.6 lps was distributed at selected nodes in the network. Intermittent as well as continuous water supply mode simulations were obtained for the current population of 4630 in the study area.

Table 2. Pipe material and roughness values

Pipe Type	Year of Installation	Hazen Willims Roughness Coefficient (C)
CI	1980	75
CI	2003 to 2011	130
DI	2003 to 2011	140
GI	2003	120
MS	1980	90

$$\boldsymbol{h_L = 4.727 C^{-1.852} d^{-4.871} q^{1.852} L} \qquad (1)$$

Where
h_L=Head loss
C=Hazen-Williams roughness coefficient
d=Pipe Diameter (ft)
q=flow rate (cfs)
L=Pipe length (ft)

2.4. Demand Calculation

2.4.1. Continuous Supply

A multistage procedure was adopted to assign base water demand to all the nodes. The number of houses around each node was manually counted by overlaying ortho-image of the study area with distribution network map. Total number of houses in study area is 926. Population data was generated by multiplying the number of houses by 5 (considering average persons in each house). Thiessen polygons were generated in ArcMap to get the number of houses around each node. The total water demand by the houses around a particular supply node was estimated assuming a constant demand of 155 lpcd (135 lpcd + 15% unaccounted for flow).

2.4.2. Diurnal pattern

One of the very important aspects of continuous water supply is the diurnal pattern which is represented as demand multiplier in EPANET. A set of demand pattern by an individual were formulated based on random consumption patterns for different uses of water in different time spans of the day. For this, demand patterns based upon the social study reported in the literature (Jethoo, 2011) were used as the basis to generate 24hr random water demand which is then subjected to rescaled range analysis (R/S analysis) to confirm the Hurst's coefficient in the range of 0.5 to 1 for persistent behavior of the series (Qian, 2004; Feder, 1999). A set of multiplier (pattern) which best suited the pilot study area was chosen for diurnal analysis.

2.4.3. Intermittent Supply

With available software head driven analysis (Table 2) for the purpose would be to replace demand nodes with equivalent diameter artificial tanks or artificial reservoirs with the hydraulic grade line (HGL) set equal to the total desired head at a particular node. This would assume that gauge pressure at the outlet in the elevated reservoir is zero. Artificial reservoir is the suitable assumption as it takes in to account water storage behavior of consumers during non supply hour. The pressure driven demand for intermittent water supply simulation is given in Eq. 2.

Table 2: Pressure dependant flow

Pressure Condition	Demand (flow)
$H_i < Hmin,i$	$Q_i = 0$
$H_i > Hmax,i$	$Q_i = Qmax,i$
$Hmin,i < H_i < Hmax,i$	$Q_i = f(H)$

$$Q_i = Q_{max}\sqrt{\frac{H_i - H_{min}}{H_{max} - H_{min}}} \quad (2)$$

Where
H_i: Pressure at a node i
$Hmin,i$: Minimum required pressure at a node i
$Hmax,i$: Maximum pressure at a node i (defined as pressure above the estate height)
Q_i: Demand at a node i
$Qmax,i$: User specified (requested) demand at a node i

2.4.3.1. Household Reservoir

As described above for intermittent simulation each demand node was represented by artificial reservoir where the total head of the reservoir is the sum of that particular node elevation and pressure head. In this way 96 artificial reservoirs were inserted in the network corresponding to the demand nodes. Terminal nodes (intermediate nodes) connected to other study area were also replaced by artificial reservoirs with suitable assumptions

2.4.3.2. Equivalent Pipe Diameter

Since the total demand of the study area was distributed among the nodes, model skeletonisation was adopted. The house tanks are supplied over the so-called "house connection pipes" from the ferule point. The diameter of all these service pipes is 15 mm. Since the individual artificial reservoir fill rates depend mainly on the headloss over the pipeline that connects the tank to the network, equivalent pipe diameter with check valve was used to control the one way flow rate.

2.5. Model Calibration and Validation

Calibration of hydraulic models for network analysis is a routine component of the building process for hydraulic models (Bahve, 1988). Recalibration of existing models is also necessary periodically to reflect physical changes in the WDS. For this purpose set of pressure and flow values recorded at strategic locations of the pilot study area were used for model calibration by trial and error method.

3. RESULT AND DISCUSSION

Model simulations were obtained initially with assumed worst case values of roughness coefficient (Table 3) and subsequently intermittent simulation was improved by calibrating the model. After calibration the correlation coefficients for observed and simulated mean values of pressure and flow rate, were estimated to be 0.999 and 0.620, respectively. During the process of calibration pipe roughness values improved significantly. The calibrated values were expected as the water supplied to the pilot area is alkaline in nature indicating less chance of pipe corrosion. Thus calibrated values for pipe roughness are considered acceptable.

3.1. Intermittent Water Supply Simulation

Since the supply duration in the pilot area is 1:30hr, neglecting the initial pipe charging process, intermittent simulation for the specific hour was conducted in the present study. During this time period, the consumption is high irrespective of the demand. Model simulation indicates that the unit head loss in the transmission main and distribution mains are 3.25 and 29.28 m/km respectively, whereas the recommended value for headloss is 4m/km (CPPHEO, 1999). Similarly the velocities in those pipes are 1.57 and 3.61 m/sec respectively. The simulated pressure in the study area ranges between 0 to 8 meter, whereas around 34 nodes show less than equal to 1 meter, which is very less than the recommended pressure value (Fig. 2). Since people are collecting water from the ground floor level, there is no problem with respect to getting water through service pipes. But people staying on the 1st and 2nd floor have to pump water from the ground storage. Water storage inside the ground (subsurface storage) without precautions can affects the water quality as the storage is vulnerable to contamination. Since the system is intermittent, leakage is low.

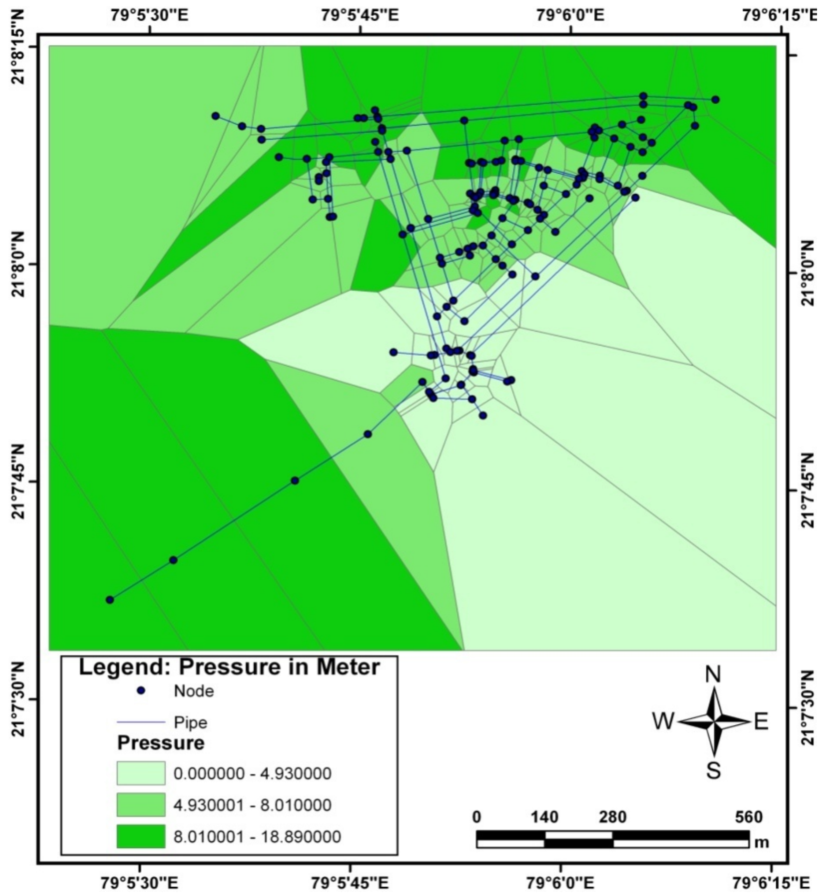

Figure 2. Pressure distribution for Intermittent Water Supply Simulations

3.2. Continuous Water Supply Simulation

For simulation of continuous mode of water supply, previously calibrated model was used. The unit head loss in the transmission main and distribution main, are 2.73 and 24.86 m/km respectively, where as the recommended value for headloss is 4m/km (CPPHEO, 1999). Similarly the velocities in those pipes are 1.43 and 3.30 m/sec respectively. During peak consumption hour the maximum observed pressure at the consumption point was 10 meter and the pressure of the study area varies from 3 to10 meter (Fig. 3)*.* Here relatively higher pressure value is obtained than the intermittent simulation, as this simulation is demand based. For the given condition the simulated leakage for continuous supply is estimated to be 4.57lps.

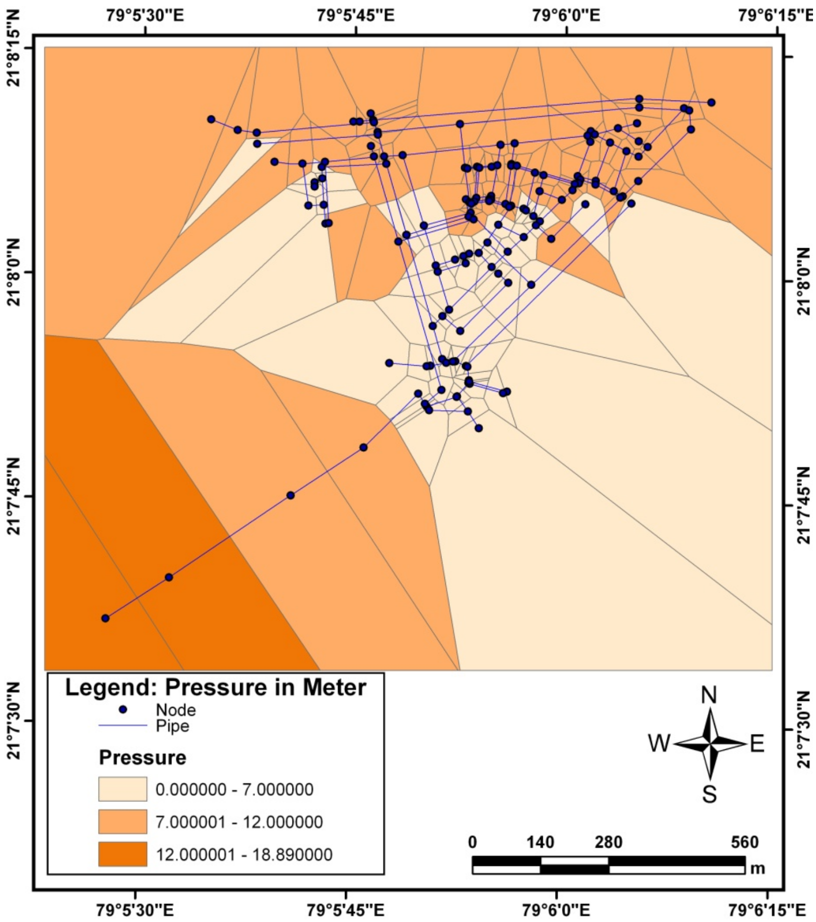

Figure 3. Pressure distribution for Continuous Water Supply Simulation

4. CONCLUSION AND RECOMMENDATION

Both intermittent and continuous water supply modes were simulated successfully using EPANET. The intermittent simulation identified that the pilot area is under very low pressure, but the leakage was less during supply hour. The continuous supply simulation results relatively higher pressure value but it is less than 12 meter. It is recommended to avoid the direct tapping of water from the transmission main, rather it is advised to build an elevated service reservoir (ESR) for the pilot study area to maintain the hydraulic integrity. The identified leakage points need to be repaired. This particular information is very essential for NMC to improve the existing system for effective pressure and flow management.

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REFERENCES

Bhave, P. R., (1988): Calibrating water distribution network models. Journal of Environmental Engineering, 114:1, pp.120–136.

Feder, J., (1988): Fractals. New York: Plenum Press.

HydroGen (Hydraulic Model Generator) Version 2.2. (n.d.). ArcScripts Home - ESRI Support. Retrieved September 1, 2012 Archive, On line at: http://arcscripts.esri.com/details.asp?dbid=10117

Jethoo, A. S., & Poonia, M. P., (2011): Water Consumption Pattern of Jaipur City (India), International Journal of Enviromental Science and Development, 2:2, pp. 152-155.

JNNURM. (n.d.). JNNURM. Retrieved September 10, 2013 Archive, On line at: http://jnnurm.nic.in/

Manual on water supply and treatment (3rd ed.) (1999): New Delhi: Central Public Health and Environmental Engineering Organisation, Ministry of Urban Development.

Ministry of Urban Development. (n.d.). Ministry of Urban Development. Retrieved September 5, 2012 Archive, On line at: http://urbanindia.nic.in/

Peter, I., Zdenek, S., Pradhan A. and Tarai A., (2006): Modeling Intermittent Water Supply Systems with EPANET, 8th Annual WD Symposium, EPA Cincinati, August 27-30.

Qian, B. R., (2004): Hurst exponent and financial market predictability. IASTED conference on Financial Engineering and Applications (FEA 2004). pp. 203-209.

Rossman, L. A. (2000): EPANET users manual. Cincinnati, OH: United States Environmental Protection Agency, Risk Reduction Engineering Laboratory.

Walski, T. M. (2003): Advanced water distribution modeling and management, Haestead Press.