Optimization of a Water Distribution System in Kenya

Agboka Komi Mensah, Alfred O. Mayabi, Charles Cheruiyot

Abstract: ***Supplying water in significant quality and quantity is still a challenge for developing countries. Juja water distribution system located in Kenya faces low-pressure and inadequate residual chlorine concentration challenges and requires capacity boosting to meet the minimum requirements of a water supply system. For optimizing the existing Juja distribution network, the current study proposes some feasible solutions. The solutions comprise of network repairs, recommissioning of an existing tank coupled with a system of chlorine booster points, an addition of a booster pump and, changes in diameters of some pipes. The analysis was carried out using Epanet 3.0 hydraulic model. The hydraulic capacity of the upgraded network met the minimum requirements of a distribution system. Pressures in the distribution system ranged between 16.91 m to 63.63 m at user points after optimization with acceptable maximum headloss of 18.24 m/km and velocity of 2.25 m/s. The hydraulic behavior of the network satisfied general guidelines. The water quality analysis showed reasonable residual chlorine concentration, with 95% of the supply area ranging between 0.40 and 0.60 mg/l after upgrade by the model. These study results were recommended and shared with the Juja water company, which is currently undertaking a review process of the supply system.***

Keywords: ***Epanet, Hydraulic analysis, Water quality analysis, water supply.***

I. INTRODUCTION

A water distribution system needs to be providing water at the desired flow and pressure and quality for users. In a water distribution system, pressures typically range from approximately 20 to 70 m. This range of pressure is a general guideline but can be used initially to analyze service area pressures [1]. Juja water supply distribution system under RUJWASCO (Riuru Juja Water and Sewerage Company) in central Kenya, is a looped distribution system but has water at user points, not at the desired pressure and flow. The residual chlorine concentration is much higher than the recommended levels in the distribution network, and results in taste and odor problems, leading to dissatisfied consumers. Therefore an upgraded distribution network is needed for an efficient supply to the consumers. The basis of optimization of a distribution network is based on cost principle and has been the subject of various research using mathematical and engineering tools[2][3][4][5][6]. The development of software based on the mathematical algorithm is widely used to solve the complexity of a distribution network. Epanet [7], has been applied by researchers for analysis in a water distribution system for simulation of hydraulic and qualitative behavior for a single or extended period in pressurized zones [8][9][10]. Epanet is a useful tool in the analysis of a water distribution system[10]. The software is easy to use, and it is a free download. A water distribution network is a set of pipes, pipe junctions, pumps, valves, and storage tanks. EPANET calculates the flow in each pipe, the pressure at each water levels in reservoirs, and the concentration of water chemicals such as chlorine in the different parts of the network, during an extended simulation. EPANET contains a modern hydraulic computing engine to calculate head losses due to friction for an extensive network. The hydraulic flow analysis is based with the assumption of flow continuity at each node in the distribution system whereby for node n, with a junction of j pipes, the flows and direction are determined by

$\sum_{i=1}^{j} Q_i - Q_{n}=0$ where Q_n is the nodal demand and Q_i is the pipe flow whereas the headloss is determined by Hazen-Williams, Darcy-Weisbach, or Chezy-Manning formula. Through Epanet hydraulic simulations environment, the tank depth and elevation can be obtained for a given volume. Water quality levels, such as chlorine concentration decay in the distribution system, can also be analysed by EPANET. The software models the chlorine decay through a first order kinetic law. Chlorine decay reactions are produced in the water mass and at the walls of the pipes. Free chlorine (HClO) interacts with the natural organic matter (NOM) of the water mass. Part of the chlorine is also transported through the surface layer of the wall to oxidize the iron (Fe) released by corrosion at the pipe wall. EPANET models chlorine in the water mass following a first order kinetic reaction constant (K_b) rate. The contribution of wall-chlorine interreactions is introduced into the software through a zero-order reaction kinetics constant (K_w). K_w needs to be adjusted to take into account the limitations on the transfer of mass of reactants and products between the water mass and the wall. Correct values of K_b and K_w coefficients have to be used through model calibration to establish required water quality parameters. The wall reaction decay depends on temperature, organic content in the water and initial disinfectant concentration [11].

Revised Manuscript Received on October 30, 2019.
* Correspondence Author
Agboka Komi Mensah *, Department of Civil Engineering, Pan African University Institute of Basic Sciences, Technology and Innovation, Kenya. Email: dilaneagboka@gmail.com
Alfred O. Mayabi, Department of Civil, Construction and Environment Engineering, JKUAT University, KENYA. Email: mayabialfred@gmail.com
Charle Cheruiyot, Department of Civil, Construction and Environment Engineering, JKUAT University, KENYA. Email: ccheruiyot@jkuat.ac.ke

The Kw of each pipe depends on the wall roughness coefficient applied [7]. Since the wall-chlorine interactions'concept is still not well understood, researchers have calibrated the K_w using various mathematical tools[12]. One of the straightforward and accurate methods is the trial-error method[13].
Storage reservoir is the service storage which helps to absorb the fluctuation in the average hourly water demand that may be due to emergencies such as fires, repairs, etc. and also maintain adequate pressure in the distribution lines. Without storage, the source of water supply would have to follow functions in the distribution system.
This study seeks to optimize the existing Juja water distribution network, through hydraulic analysis using the Epanet hydraulic model and propose an efficient upgraded system. The upgraded network characteristics were estimated based on the minimum desired pressure in the distribution network and the results and recommendations shared with RUJWASCO. The booster pump capacity was obtained in the software environment through predefined pressure range in the systems.

II. MATERIALS AND METHODS

A. Hydraulic analysis

The supply area with regional districts and existing tank currently not in use location is illustrated in Fig.2.1. The existing tank characteristics were used in the hydraulic analysis. The tank is rectangular and localized in Joyland district (278508.07; 9878050.51) with a base elevation of 1522m and height of 12 m. The tank volume is 110 m^3 which is within the margin defined by Kenyan regulation [14].

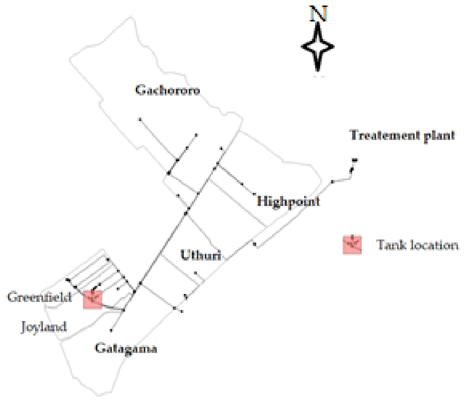

Fig. 2.1 Supply districts and existing tank location

The hydraulic model supporting this study is the existing Juja district main lines network developed under EPANET 3.0.
A water distribution network is a set of pipes, pipe junctions, pumps, valves, tanks. EPANET was used to calculate the flow in each pipe, the pressure at each water levels in reservoirs, and the chlorine concentration of water in different parts of the network, during an extended simulation. The head loss due to friction was also calculated using Epanet hydraulic computing engine, based on, Darcy-Weisbach formula for an extensive network.
To determine the booster pump required to achieve the desired minimum head of 15 m to the Gachororo district, the model was used to input pump characteristics (Fig. 3.1), H-Q values as well as pipe diameters under the Epanet environment by trial and error procedure until the desired system pressures are obtained as illustrated in Fig.3.2.

B. Water quality analysis

For the water quality analysis, the model was run with Kb and Kw value respectively equal to -0.047 and -0.021 already available in the model. The analysis was done, with various inputs of chlorine concentrations added to tanks in order to achieve the minimum residue value of 0.2 mg/l in the system.

III. RESULT AND DISCUSSION

This section provides the results obtained after a hydraulic and water quality analysis using Epanet software.
Booster pump characteristics presented in Fig.3.1 showed pressures of between 16 and 64m could be maintained in the system, thereby boosting pressures in higher ground locations.

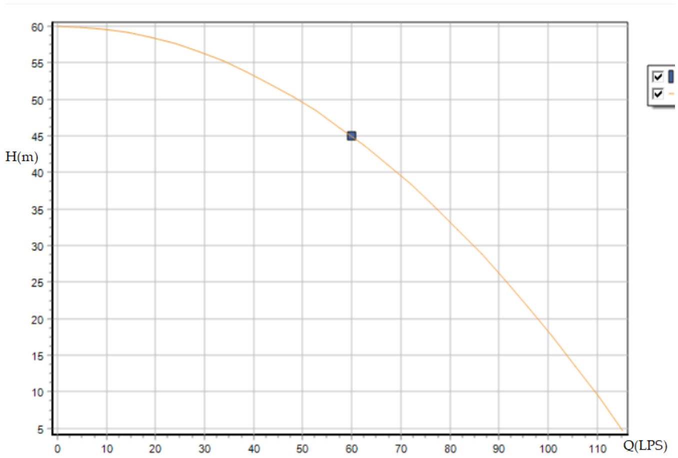

Fig. 3.1 Booster pump curve From EPANET(Head /flow)

A. Hydraulic analysis

Figures 3.2, 3.3, 3.4, and 3.5 show excellent hydraulic performance during the peak hour on the maximum consumption day. The system operation is stable. The maximum pressure of 97 m appears in node 26 nearest the treatment plant and pressure slightly drops to 16.91 m at the end of the distribution system at node 1 (Fig. 3.2 and 3.3), which is within the acceptable range of 20 to 70 m. It is recommended to avoid excessive water pressure in pipes to preserve pipes integrity for a good distribution network.

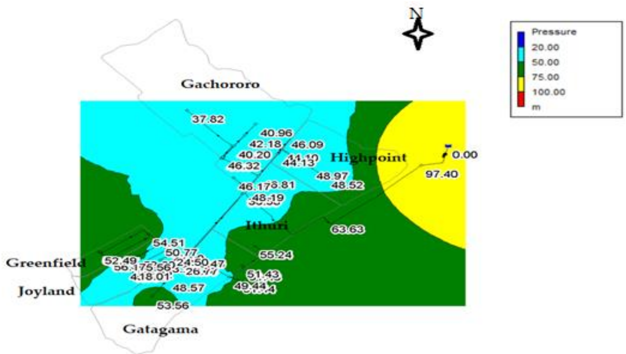

Fig. 3.2 Pressure distribution at user points

Retrieval Number: A1158109119/2019©BEIESP
DOI: 10.35940/ijeat.A1158.109119
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

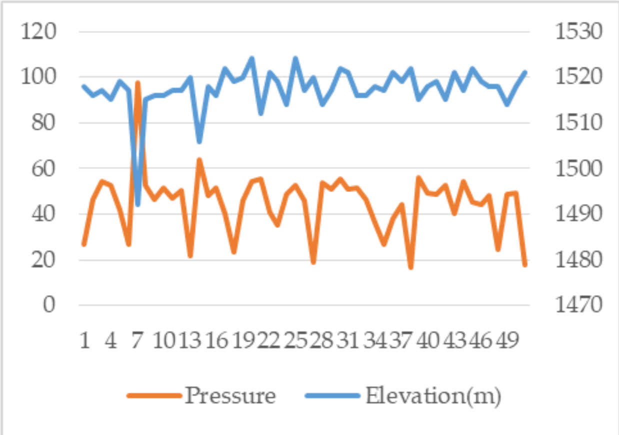

Fig. 3.3 Pressure/elevation at network junctions.

The maximum velocity in the system is 2.25 m/s (Fig. 3.4), which is typically within the guidelines ranges. A typical range of velocities in distribution pipes is between 0.5 and 1.0 m/s, and occasionally up to 2 m/s[15]. A pipe with shallow velocity/pressure head is a potential source of water quality problems and should, therefore, be reduced in diameter. Pipes in which the water stagnates play no role in a proper distribution network. These can be removed without significant implications for the overall hydraulic performance of the network unless needed for service connections or as a reliability provision. Also, Pipes with extremely high velocity/pressure head require high energy input for distribution and should, therefore, be increased in diameter.
The head-losses in the pipes are normal (Fig 3.4), suggesting that the diameter of 4inches adopted is suitable with a typical maximum value of around 18m/km. The Unit headloss should generally range between 1 and 5 m/km, occasionally up to 10 m/km[15]. However, pipes replacement with a larger diameter pipe may not be economically justified. If reliability is an issue, then larger diameters may economically be justified.

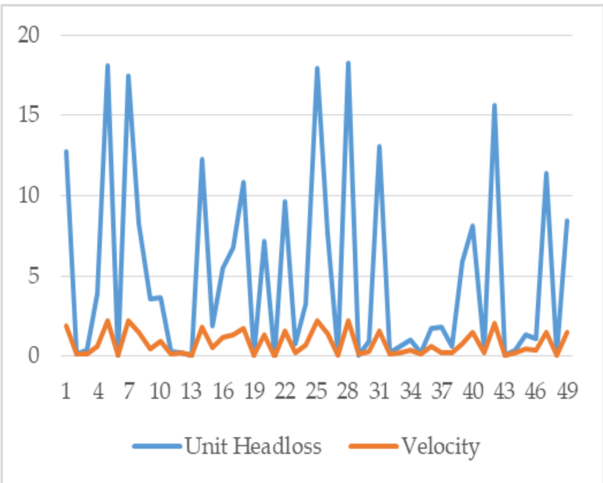

Fig. 3.4 Flow velocity /Pipe headloss in the system

B. Water quality analysis

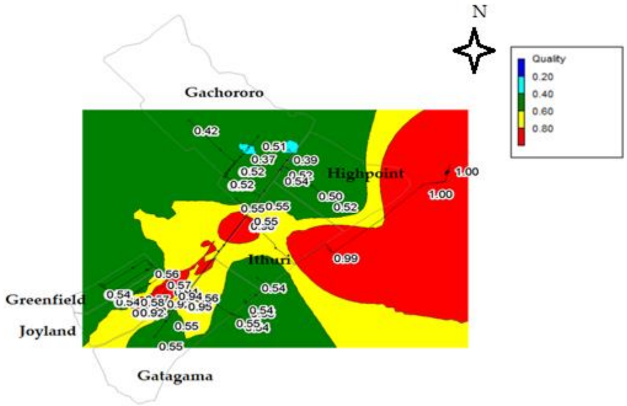

Fig. 3.5 Concentration tie-lines of chlorine throughout the system.

Fig. 3.5 shows the chlorine concentration map. The water supply chlorine residue concentration appears acceptable, with 95% of the supply area under a reasonable range of between 0.40 and 0.60 mg/l. This is above the minimum recommended by the WHO and at the same time, solves the taste and odour problems that were experienced by the consumers before the optimization of the system [16].

IV. CONCLUSION

The distribution system operation was stabilized with mild variations in pressures throughout the network. Flow velocities achieved after optimization was between 0.5 and 2.25 m/s that is satisfactory.
The upgraded system is shown reasonable head losses with a rarer maximum of 18m/km while averaging between 3m/km and 6m/km.
The chlorine concentration in the upgraded system was within acceptable limits of 0.4 to 0.6 mg/l.
By introducing the balancing tank storage, it is reasonable to expect that the pumping costs in this proposed scheme of supply will be lower than the direct pumping previously done. The maintenance costs will also be lower compared to the existing one. Once the upgraded system is implemented, the Juja consumer will enjoy better services in terms of water in quantity and quality. It should also be noted that implementing such a proposal without regular maintenance will solve the problem for a limited lifetime. It is crucial to think about equipping developing countries with a drinking water network Real-time monitoring (RTM) system for better quality control. RTM application for water distribution systems is the latest update on such fields. This proposal was recommended and shared with the water company in charge of Juja, and its implementation is in process. The future work will focus on developing a low-cost real-time monitoring system for quality control of a distribution network.

REFERENCES

1. S. S. Nation, "Potential Water Distribution System Pressure Zone Layout And Preliminary Review of Fireflow Requirements Feasibility Study for Water Supply System," no. October 2006.

2. A. D. Bello, W. A. Alayande, J. A. Otun, A. Ismail, and U. F. Lawan, “Optimization of the designed water distribution system using MATLAB,” *Int. J. Hydraul. Eng.*, vol. 4, no. 2, pp. 37–44, 2015.
3. A. Ben-Tal, “Design of optimal water distribution systems,” *Water Resour. Res.*, vol. 30, no. 4, p. 2637, 1994.
4. J. Krope, D. Dobersek, and D. Goricanec, “Flow Pressure Analysis of Pipe Networks with Linear Theory Method,” *WSEAS/IASME Int. Conf. Fluid Mech.*, vol. 2006, no. 1, pp. 59–62, 2006.
5. I. Sârbu, “Optimization model of water supply networks design,” pp. 108–113.
6. I. Sarbu and E. S. Valea, “Optimization of water distribution networks path,” *ARPN J. Eng. Appl. Sci.*, vol. 8, no. 5, pp. 333–337, 2013.
7. U. S. E. P. Agency, “Epanet 2 users manual,” no. September 2000.
8. G. Anisha, A. Kumar, J. A. Kumar, and P. S. Raju, “Analysis and Design of Water Distribution Network Using EPANET for Chirala Municipality in Prakasam District of Andhra Pradesh,” no. 4, 2016.
9. I. Gupta, R. K. Khitoliya, and S. Kumar, “Study of Water Distribution Network Using EPANET,” pp. 58–61, 2013.
10. A. Kumar and V. Thakur, “Design of water distribution system using epanet,” no. October 2015.
11. I. Stoianov and A. Aisopou, “Chlorine decay under steady and unsteady-state hydraulic conditions,” *Procedia Eng.*, vol. 70, no. 0, pp. 1592–1601, 2014.
12. A. T. Tiruneh, A. O. Fadiran, S. J. Nkambule, and L. M. Zwane, “Modeling of Chlorine Decay Rates in Distribution Systems Based on Initial Chlorine , Reactant Concentrations and Their Distributions,” vol. 3, no. 3, pp. 53–62, 2016.
13. P. Castro and M. Neves, “Chlorine decay in water distribution systems case study–Lousada network,” *Electron. J. Environ. Agric. Food Chem.*, vol. 2, no. 2, pp. 261–266, 2010.
14. P. Manual, “WATER SUPPLY,” no. October 2005.
15. “21 Water distribution Nemanja Trifunovic.”
16. G. I. Bassey, “Residual Chlorine Decay In Water Distribution Network,” no. October 2016.