Results in Engineering 5 (2020) 100100

Contents lists available at ScienceDirect

Results in Engineering

journal homepage: www.editorialmanager.com/rineng/Default.aspx

# Analysis and optimization of water distribution systems: A case study of Kurudu post service housing estate, Abuja, Nigeria

O.M. Awe [a,*], S.T.A. Okolie [a,b], O.S.I. Fayomi [a,c]

[a] Department of Mechanical Engineering, Covenant University, Ota, Ogun State, Nigeria
[b] Department of Mechanical Engineering, Gregory University, Uturu, Abia State, Nigeria
[c] Department of Chemical, Metallurgical and Materials Engineering, Tshwane University of Technology, Pretoria, South Africa

A R T I C L E I N F O

*Keywords:*
Water distribution system
Sustainable development goals
Optimization
Water
Hydraulics
Epanet
Lingo

A B S T R A C T

In a bid to impact the 6th goal of the 17 sustainable development goals, this study models and optimizes the water distribution systems (WDS) case study by using the water distribution system layout to estimate the water demand, model flow, velocity and head loss for the case study using EPANET software and finally optimizing the system using LINGO software. The optimization algorithm developed herein is characterized by seeking out the optimal least cost system parameters which ensures that the systems serve its purpose efficiently with hydraulic and heuristic rules and constraints normally used for pipeline design are satisfied and employed in the model in other to achieve the optimum solution. The model representation of the existing water distribution system was solved by using initial pipe diameters of 150, 200, 250, 300 and 400 mm size, the pressure generating elevation of 25, 30 and 35 m head characteristics. The problem evaluates seamlessly and the total run time was 0.23 s. Results showed that the optimum reservoir height is 25 m while the optimum pipe diameter was determined to be 300 mm and consequently a 38% reduction in total cost of installation, operation and maintenance of the Water distribution system (WDS).

## 1. Introduction

Rapid urbanization and exponential increase of demand for water are some of the challenges that the 6th sustainable development goals seeks to offset [1] and this challenges require water distribution systems (WDS) to be increasingly efficient. WDSs are systems which usually contains interrelating modules such as pumps, pipes, valves, pumps, reservoirs and tanks and are a result of combined efforts of engineers and scientists around the world [2]. The reliability of WDS is dependent on system configuration, design, pressure and flow through the systems elements. Water distribution system operational costs may be greater or equal to 60% of the entire cost of the entire system[3].

Water Distribution Systems are still operated using simplifying assumptions and rigid-static analysis. As a result, the systems are not tested under various conditions, which can be encountered during its operational life, and under different water demand scenarios [4]. This usually generates alarming failures in meeting the actual demand during the operation of the system in real life situations.

Continuous efforts should be made to drastically reduce waste/abuse, contamination [5,6]and systems operational cost through optimization, analysis and design. Several popular optimization and assessment techniques can be used to analyze a water distribution system. These methods may include several stochastic and metaheuristic methods [6].

Inadequacy of water distribution systems to satisfy demand and pressure usually is as a result of population increase, which is mainly caused by rapid urbanization. Another problem is pipeline leakage and disruption due to bursts. High pressure and flow frequently lead to burst, water loss, reductions in water quality, high maintenance costs, Poor systems design as a result of systems being designed as a continuous system that relies on the steady supply assumption [7]. However, water supplies are not continuous but intermittent. Poor System design and configuration make WDSs vulnerable to errors due to incorrect assumptions, insufficient statistics and input calculation errors. The associated high levels of contamination are a serious problem caused by the intermittent supplies, bursts and leakages. This is done in systems where supply interruption periods are prolonged due to insignificant or null pressures on a system and frequent system disruption [8–10].

This research uses data driven methods to optimize water distribution systems with immense environmental and sustainability impact. In other words, it develops an analysis of water distribution system case study and

* Corresponding author.
*E-mail addresses:* michael.awe@stu.cu.edu.ng (O.M. Awe), ojo.fayomi@covenantuniversity.edu.ng (O.S.I. Fayomi).

https://doi.org/10.1016/j.rineng.2020.100100
Received 20 October 2019; Received in revised form 10 January 2020; Accepted 12 January 2020

optimizes the system using a linear model to achieve optimal solution. The case study area chosen is a perfect pitch for this research because of its location and persistent challenges experienced in its daily activities of water storage and distribution. Some of the challenges which include water shortages, poor design and high costs are tackled and minimized through the methods used in this research. The optimization is based on linear programming and enables the optimum distribution of commercial diameters along the length of each pipe and the length of pipes corresponding to those diameters to be determined The main objectives are examination of the water distribution system (WDS), modeling of flow, velocity and head loss for the water distribution system (WDS) using EPANET and optimization of water distribution system using LINGO.

### *1.1. Impact of WDS optimization and analysis on SDGs*

The sustainable impact assessment is a framework which enables the evaluation of the impact of different methodologies that can be applied. Assessing direct or connected impact on SDGs may be difficult because it contains uncertain characteristics. Therefore, the assessment should have it basis on society, economic and environmental objectives as in Fig. 1. The assessment of the impact on sustainable development goals is dependent on scope, reach and data available for the study. Hence, the study is innately subjective and exploratory, and open for further studies.

Developing countries are usually with inaccessible resources or data for accurate monitoring and also have more needs, major gaps between present potentials and the targets [12].

Data driven research methodologies and results play a major role in facilitating continuous assessment of impact and consequently achieving the sustainable development goals on all levels. This study addresses partly the challenges related to implementation, cost, hydraulic incapabilities, and monitoring of the present reality with targets of the SDGs.

## 2. Methodology

### *2.1. Case study*

Post service housing scheme (PSHS) largely covers the major part of Kurudu which is one of the largest areas in AMAC local government areas in Abuja. It has an area of about 940 ha. It is located in the southeast region/outskirt of the Federal capital territory with x, y coordinates (8.9410438 7.5493254) with elevation of 630 m above sea level. Post service housing scheme (PSHS), Kurudu as shown in the area bounded in the Fig. 2 is an estate development which contains an estimated 1520 buildings and house about 15000 people.

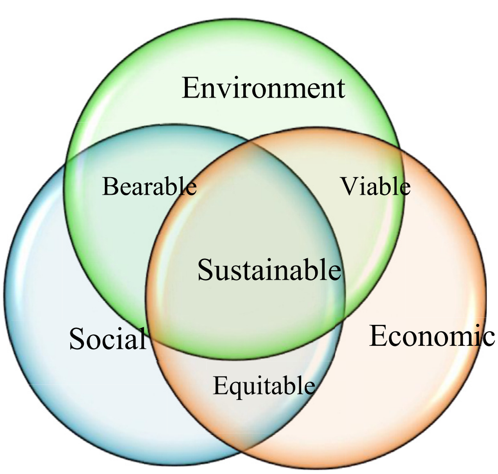


**Fig. 1.** Objectives/dimensions of sustainable development [12].

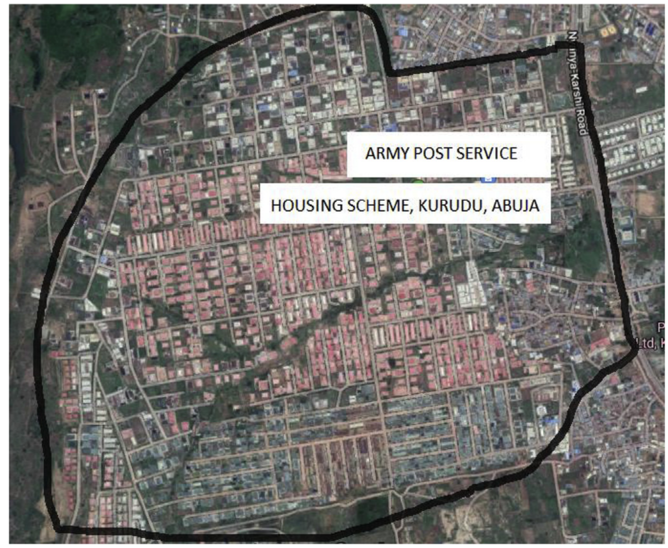


**Fig. 2.** Satellite map of Post service housing scheme, Kurudu, Abuja.

### *2.2. EPANET and LINGO*

The major aim of this research is to analyze, model and optimize the water distribution system (case study) so as to comprehend and improve the complex system. The main objectives include: Examination of the study area water distribution system (WDS) by modeling of flow, velocity and head loss for the system using EPANET and also optimization of water distribution system using LINGO.

EPANET is a tool used across borders to model, analyze and evaluate water distribution sys-tems (WDS). It is a software used to execute high end simulations on WDSs detailing it be-havior hydraulically and quality wise across closed and pressurized WDSs which usually con-tains modules or components such as pumps, pipes, valves, storage tanks, and reservoirs.

LINDO (Linear, Interactive, and Discrete Optimizer) systems develop software tools for op-optimization modeling. LINDO offer solvers and a featured environment for Integer Program-ming, Linear Programming, Nonlinear Programming, and Global Optimization models. LIN-DO systems products include Lindo API, LINGO, and What'sBest for Excel. This product primarily differs in terms of how models are expressed and how you interface with them [11].

LINGO is a software which helps to search for the best solution in an optimization problem with well-defined constraints in the fastest possible time. LINGO expresses the model using modeling language. In order to express large models quickly, the modeling language supports summations and subscripted variables. LINGO is of the ability to read data from and write solution information to Excel or Microsoft Access. LINGO also entails a user interface for interactive use and a callable programming interface that allows you to embed LINGO in your own application.

### *2.3. Water demand estimation*

The water distribution system in consideration is displayed in Fig. 3 and the estimated water demand for the estate was determined from the parameters in Table 1.

Estimated water demand for the estate was determined as follow; Water Demand (WD): Population × Demand value;

Municipal average water demand: Constant Demand Value × Population [7].

Municipal average water demand = 120 X 14526 = 1743120 L/day;

Adopting peak hour factor of 2 = 1743120l/d x 2 = 3486240 L/day for the WDS;

**Fig. 3.** Post service housing scheme, Kurudu Water Line layout draft.

**Table 1**
Case study area parameter (post service housing scheme, Abuja).

| Case Study Area Parameter (Post Service Housing Scheme, Abuja) | |
|---|---|
| Parameters | Values |
| Average Household Population | 7 |
| Total Number Of Buildings | 1520 |
| Total Number Of Households | 1858 |
| Estimated Current Total Population | 14526 |
| Expansion Capacity | 30000 |
| Average Water Demand | 1743120 L |

### 2.4. Optimization method

This method minimizes the cost of the installation and operation of the system while satisfying demand and hydraulic criteria. Some of the factors to be determined include the pipe diameter, corresponding pipe lengths, and number of links. This approach is derived from a modified model by Ref. [7] as shown in the objective function and constraints.

### 2.5. Objective function

The objective function used to minimize the system cost for the case study for this research; Kurudu estate, water distribution system was formulated using research work done by Ref. [8];

$$TCC = l(D_N) + h(R_K) \tag{2.1}$$

Where $l(D_N)$ symbolizes the expenses of pipes and their installations which is a function of pipe diameters $D_N$, and $h(R_K)$ representing the cost of pressure generating facilities (i.e. reservoirs and pumps) which is a function of reservoir height or dynamic head.

These can be expressed as below:

$$l(D_N) = \sum_{N=1}^{N_p} L_n PC_n \tag{2.2}$$

$$h(R_K) = \sum_{k=1}^{N_b} BC_K \tag{2.3}$$

Where.

$L_N$ = pipe length numbers N,
N = represents pipe number label in the system.
$PC_n$ = Unit pipe length cost N (function of pipe diameter$D_N$),
$BC_K$ = cost of pressure generating facility unit K, and is a function of $R_K$
$N_p$ = system total number,
$N_b$ = number of pressure generating facilities in the system

Putting equations (2.2) and (2.3) in equation (2.1) gives;

$$TCC(R_K, D_N) = \sum_{N=1}^{N_p} L_n PC_n(D_N) + \sum_{k=1}^{N_b} BC_K(R_K) \tag{2.4}$$

Multiplying equation (2.4) by zero-unity variables $X_{Ni}$ and $Y_{jk}$ and including them for all pipes, reservoirs or pumps that are commercially available gives;

$$TCC(R_K, D_N) = \sum_{i=1}^{NCA} \sum_{N=1}^{N_p} L_n PC_n(D_N) X_{Ni} + \sum_{j=1}^{NBA} \sum_{k=1}^{N_b} BC_K(R_K) Y_{jk} \tag{2.5}$$

Where;

NCA = number of pipes that are commercially available
NBA = number of reservoir or pumps (pressure generating components)

When $X_{Ni}$ in equation (2.5) is equal to zero means that the corresponding commercial pipe size is not included and likewise for $Y_{jk}$. Equation (2.5) is subject to the following constraints.

### 2.6. Constraints

The main objective function as expressed in (2.5) was subjected to the constraints listed below [8];

- Satisfaction of water demands (flow and pressure parameters)
- Satisfaction of flow through nodes(nodal parameters such as elevation and head)

For every pipe in the system, Equation (2.5) should include all commercially available pipe sizes such that optimal solutions give realistic and implementable solutions. Only one size will be found as solution for each branch in the system i.e. just one of the variables $X_{Ni}$ for a given N will be equal or allocated to unity variable. Hence, the constraint should be taken into account for every branch in the system:

$$\sum_{i=1}^{NCA} X_{Ni} = 1 \tag{2.6}$$

Similarly, the constraint for pressure generating facilities may be expressed as:

$$\sum_{j=1}^{NBA} Y_{jk} = 1 \tag{2.7}$$

#### 2.6.1. Pressure constraint

When considering pressure constraint, the reference node should first be defined. Usually the reference node represent the location of a pressure generating facility results as:

$$p_i = H_R - \Delta Y_{R-i} - \sum_{i-NCP}^{m} HL_i \tag{2.8}$$

Where;

$p_i$: Head pressure at node I,

$\Delta Y_{R-i}$: Difference in height of the reference node and node I,
$H_R$: Reference node head,
NCP: number of pipe connected to the reference node in the path R–I,
M: number of pipes of the path R-i
$\sum_{i-NCP}^{m} HL_i$: Addition of head-losses across reference node and end at node i,
$p_i$ Can only range from stated limits as expressed below;

$$p_i \leq p_{max} \tag{2.9}$$

$$p_i \geq p_{min} \tag{2.10}$$

Substituting equation (2.8) in (2.9) and (2.10) gives;

$$H_R - \Delta Y_{R-i} - \sum_{i-NCP}^{m} HL_i \leq p_{max} \tag{2.11}$$

$$H_R - \Delta Y_{R-i} - \sum_{i-NCP}^{m} HL_i \geq p_{min} \tag{2.12}$$

Applying the zero-unity variables to equation (2.11) and (2.12), we have;

$$\sum_{M=1}^{NRA} H_R Y_{jk} - \Delta Y_{R-i} - \sum_{i-NCP}^{m} HL_i X_{Ni} \leq p_{max} \tag{2.13}$$

$$\sum_{m=1}^{NBA} H_R Y_{jk} - \Delta Y_{R-i} - \sum_{i-NCP}^{m} HL_i X_{Ni} \geq p_{min} \tag{2.14}$$

#### 2.6.2. Velocity constraint

Velocity and flow constraints are expressed as;

$$V_{min} \leq V_n \leq V_{max} \tag{2.15}$$

Where $V_{min}$and $V_{max}$ represent allowable velocities and flow within the pipes. Applying zero-unity variables and inputting for the velocity expression (2.16) in terms of flow $Q_n$ and diameter $D_n$ gives:

$$V_{min} \leq \sum_{i=1}^{NCA} \frac{Q_n}{\frac{\pi}{4} D_{Ni}^2} X_{Ni} \leq V_{max} \tag{2.16}$$

### 2.7. Optimization analysis by integer linear programming

The objective function represented in equation (2.5) subject to the constraints indicated in equations (2.13), (2.14) and (2.15) and (2.16) should be minimized so as to achieve the optimum design which finds the least total cost. In this typical optimization problem, the zero unity variables which are integers are the unknowns. Afterward, the integer linear programming was applied using LINGO optimization software. The LINGO computer program uses both binary branch and bound method of integer linear programming to search the optimal solution space.

#### 2.7.1. Assumptions

- This research assumes the cost values of pipes and other water utility value in dollars ($) since the research intends to analyze the effect of optimization on the system. The effect can be presented in percentages. With this, we will be able to make an adequate decision through the analyzed effect.
- Low Water velocity, pressure, increased head loss are the major factors causing Water shortage and inefficiency in the distribution of water in water distribution system (WDS).

### 2.8. Linking hydraulics model with optimization analysis

In order to carry out the optimization analysis, the optimization equations should explain that the pipes flow into the water distribution system should be known. Pipe flow releases can be determined by applying the continuity equation at nodes in branched configuration systems while in looped systems. The following are the steps taken during the optimization of the problem.

- Stated diameters of pipes and reservoir heights ensuring only commercially available pipe parameters are stated.
- Performed the WDS analysis to get data for heads, flow and head loss using modelling software (EPANET)
- Replaced the flow evaluated from step 2 in velocity and pressure constraint expression ((2.13), (2.14) and (2.16)
- Used linear integer programming solver in LINGO for minimizing the objective function equation (2.5) subject to the constraints [equations (2.6), (2.7), ((2.13), (2.14) and (2.16)] to solve for $Y_{jk}$ *and* $X_{Ni}$ and get the optimal pipe diameter and pressure generating facility heads.
- Compare optimum solution with the existing ones. If the differences are less than acceptable tolerance limits then the problem is solved.

## 3. Results and discussion

### 3.1. Model result (flow, velocity and head loss)

The water distribution system was modelled for the case study (Post service housing estate, Kurudu) for 24 h supply using the EPANET Version 2.0 with appropriate pipe diameter as shown in Fig. 4. After application of the software the following summary were obtained.

Summary of Water distribution system (WDS).

Number of Junctions 1708
Number of Reservoirs 1
Number of Tanks 0
Number of Pipes 1763
Number of Pumps 1
Number of Valves 0
Flow Units LPS

### 3.2. Results analysis

During the analysis, the system indicated negative pressures while in operation. It was also noticed that the distribution was intermittent in certain areas of the water distribution system. As far as the Abuja municipal water board and PSHS water distribution system is concerned they were not providing a constant 24 h supply to all consumers. Hence as an improvement over the first analysis, the same system is analyzed using EPANET. There were several aspects taken into consideration in designing the water distribution system. These aspects include pressure, head, elevation, pipe diameter, pipe lengths, etc. the system was analyzed for 24 h period distribution and satisfaction of the customer in obtaining the water at the tail end without any loss of pressure. The system was analyzed for intermittent supply because there is always a shortage of water at a certain portion of the study area. The system showed negative pressure in some areas of the water distribution system (WDS) when analyzed for intermittent supply.

Pipe size in terms of diameter and length have an effect on head loss [9]. In the water distribution system, the diameters of sub-main lines at the post service housing scheme (PSHS) have a diameter greater than 75 mm. 6.6% of the entire pipe diameters are 32 mm, 56.4% of the pipes are less than 100 mm and this is the percentage of pipes that actually supply water to end users. 11.7% of the pipe diameter is the sub-mains which are greater than 75 mm in size. The mains of the system are 400 mm size diameter and they are less than 1% of the pipe diameters available in the WDS.

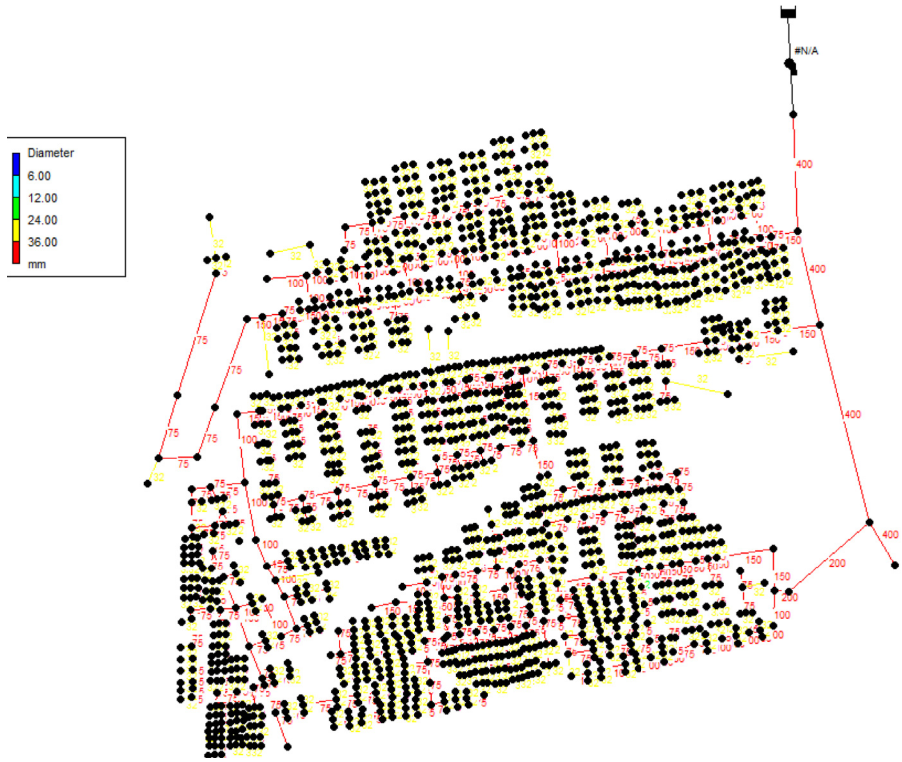


**Fig. 4.** Configuration representing study area and showing pipe diameter.

The average head losses of these pipes in the water distribution system (WDS) was calculated to be 109 m/Km. 13.5% of the pipes have head losses greater than average estimated head loss. The pressure distribution is not an illustration of pressures at taps only, but it includes the pressure at all different nodes in the water distribution system. The pump curves and reservoir heads were displayed during the system analysis.

In the water distribution system, there were areas marked by high and low pressure, so that water supply is not reliable, this means that the systems could experience bursts and leakages in areas with high pressure and water shortage in areas of low pressure over a period of time. Here, the water supply problem is due to the inadequacy of pressure in the pipes and water shortages in certain areas of the system. Through linear optimization, we ensure optimal pressure in distribution systems.

The average estimate of 13.2 L/s in flow and 1.6 m/s in velocity transport water through the water distribution system. Fig. 5 also shows the flow in selected pipe 12 throughout the simulation period of 24 h. It is, however, worthy to note that as the flow peaked at about 8:00, the pressure reduces at the same period.

Pressure and pressure gauge at every point of any water distribution system is very necessary, else the water distribution system (WDS) will not be able to deliver water to the end user. Fig. 6 shows the pressure performance in node 1479. The haphazard look of the graph depicts clearly the intermittent distribution in the system. The graph showed that there could be a shortage of water at a specific period, and even more especially when the demand unexpectedly increases in these times or period. This same pattern can be seen in Fig. 7 with pressure profile of 5 selected nodes turning out with the same pattern.

Fig. 8 shows the velocity of water passing through the pipes over a time series of 24 h. The graph shows that velocity is high in high-pressure pipes such as in link (pipe) 15. This increased velocity is due to the fact that water is been tapped from a high-pressure pipe of 400 mm using a pipe of 150 mm other pipes show considerable lower velocity because they are service pipes and water would have circulated to other parts of the system thereby reducing the velocity.

Figs. 9 and 10 represents the graph of unit head loss and pressure on specific selected junctions or nodes in the WDS. The head loss in Link

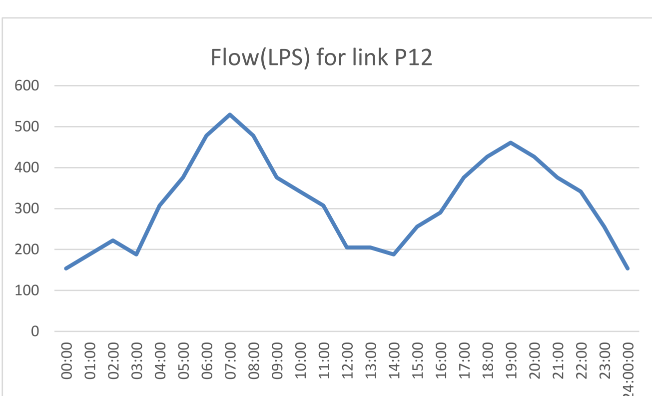


**Fig. 5.** Flow time series for pipe 12.

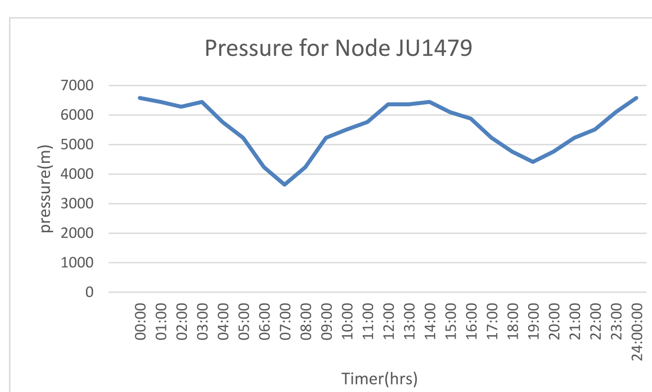


**Fig. 6.** Pressure at node 1479.

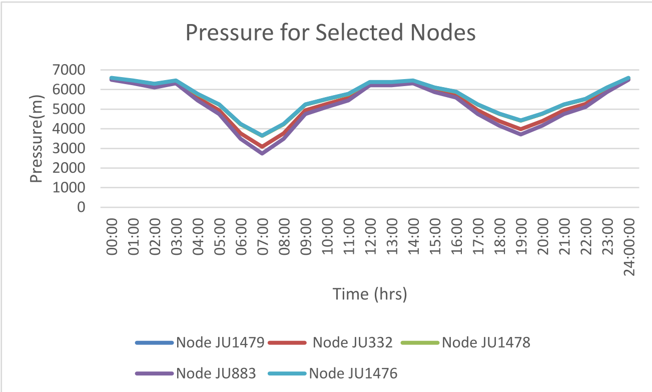


**Fig. 7.** Nodal pressure at 5 selected junctions.

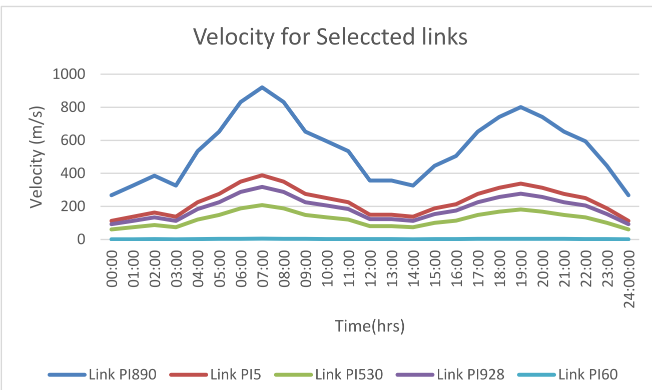


**Fig. 8.** Velocity of selected nodes.

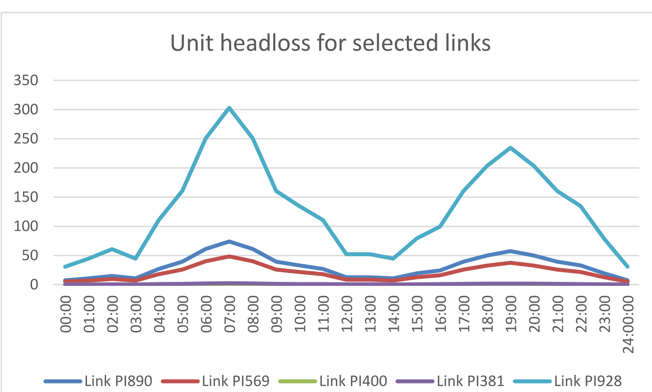


**Fig. 9.** Unit headloss for selected pipes.

(pipe) 1381 happens to be out of range and extreme and this may signify a possible pipe breakage or burst. This burst or breakage which caused the increased unit head loss might also be the sole reason for pressure drop at about the same time in Fig. 10.

In order to understand the behavior of water transmitted through the water distribution system (WDS) over a period of time, a breakdown of the simulation is shown within two crescents (Gen S.A Gbogha Crescent and GaniyuMuhammed Crescent) in the Post Service Housing Estate, kurudu. An expanded view of this areas/crescents is shown in Figs. 11 and 13.

As conspicuously shown in Fig. 12, Gen S.A Gbogha Crescent experiences some negative flow of water which naturally causes a shortage in that area of the system. This occurs basically due to the high altitude of

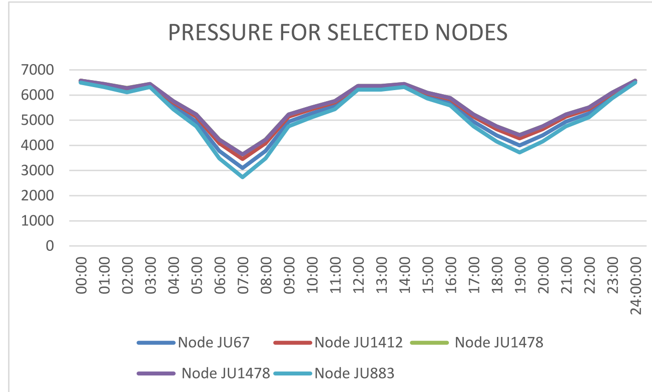


**Fig. 10.** Pressure for selected pipes.

the area. Whereas, GaniyuMuhammed Crescent with the model result as below, has a much better flow and the system can be seen as balanced enough to always distribute water at the required pressure and flow to the fixtures within the buildings and constantly meet demand.

As we see in the graphical representation in Fig. 14, there is no negative flow and velocity and headloss in GaniyuMuhammed Crescent seems balanced enough. Finally, EPANET generated a system flow balance of the entire water distribution system as shown in Fig. 15. This graph is a direct indication that the existing system is grossly unbalanced and not efficient in conveying water to meet demand in all areas of the system. The unbalance nature and inefficiency in the current WDS leads us to the optimization of the system.

### 3.3. Optimization

The result of linking the hydraulic analysis with the optimization model produced a unique optimization problem which was solved using LINGO 18.0 version, a subsidiary of LINDO systems, the model reveals that the unknowns are the zero-unity variables, which are integers and pressures at nodes which are real. The LINDO system (linear, interactive, discrete optimizer) software application was used in this research to search the optimum design solution and equitably allocate resources. This program solves for $X_{Ni} Y_{jk}$ *and* $p_i$, nodal pressure variables such that total cost is reduced. Using evaluated zero-unity variables, the corresponding pipes, and the pressure generating facility was obtained.

A linking of hydraulic and optimization solvers was proposed by Samani and Mottaghi[8]. Below are the results and proceeds of the optimization of the existing mains of the water distribution system.

Applying the integer linear programming solver for problem results in:

$$X_{10} = 0.000000,\ X_{11} = 0.000000,\ X_{12} = 1.000000,\ X_{13} = 0.000000$$
$$X_{14} = 0.000000,\ Y_{11} = 1.000000,\ Y_{12} = 0.000000,\ Y_{13} = 0.000000$$

Hence, the optimum pipe size and reservoir height was estimated to be; D = 300 mm HR = 25 m. The minimized cost of purchasing, installing and maintaining the systems; TC = 190000 dollars ($) compared with the gross value of 305500 dollars ($) before optimization. We can deduce that if the optimized design is implemented, the system will satisfy all hydraulic specification in every part of the system and yet reduce cost by approximately 38% as presented in the Fig. 16.

A municipal pipe system's total cost objective function and constraints are usually nonlinear. Nonlinear programming is a common optimization method to solve such problems. However, achieving an optimum solution by using nonlinear programming is not assured [9]. Optimization methods employing linear programming are quite effective to generate the optimal solution directly and quickly. In this study, we linearize the nonlinear cost objective function and the constraints by using zero-unity

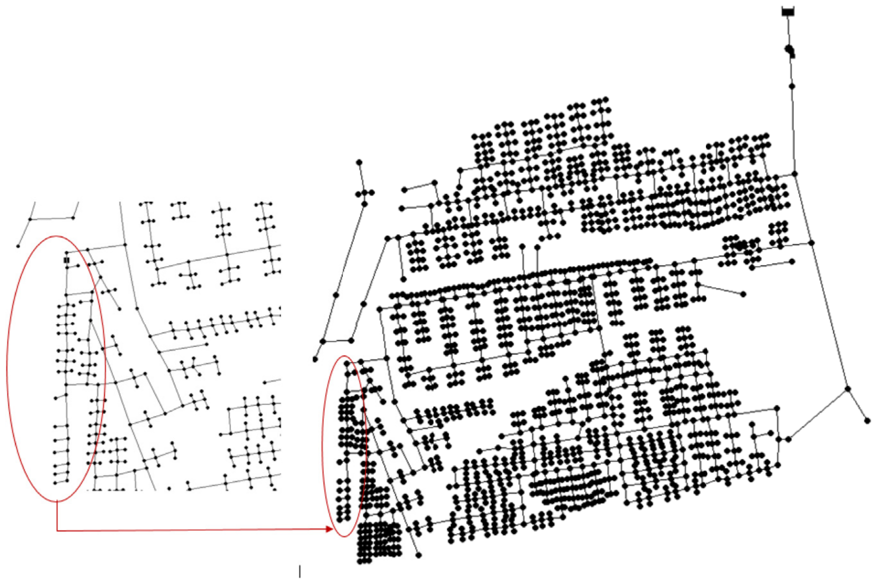

Fig. 11. Gen S.A Gbogha Crescent.

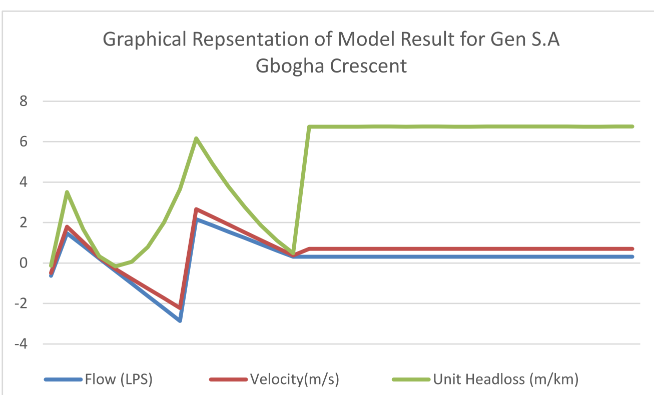


Fig. 12. Graphical representation of model result for Gen S.A Gbogha Crescent.

variables. This enables us to use the integer linear programming for solving optimization problems of municipal systems in which obtaining the global optimum is assured.

## 4. Conclusion

The water distribution system of the case study was analyzed to show and represent the capabilities of the proposed model. The case study is an estate developed in the southeast region of the federal capital territory, Abuja Nigeria. The system consists of one reservoir, 1763 pipes and one pump, which is between reservoir RE1 and Node JU1480. All pipes are assumed to have a Hazen–Williams coefficient of 150.

The optimization algorithm developed herein is characterized by the following features; the method seeks out the optimal least cost system parameters which allows the systems serve its purpose efficiently with hydraulic and heuristic rules and constraints normally used for pipeline design are employed in the model in other to achieve the optimum

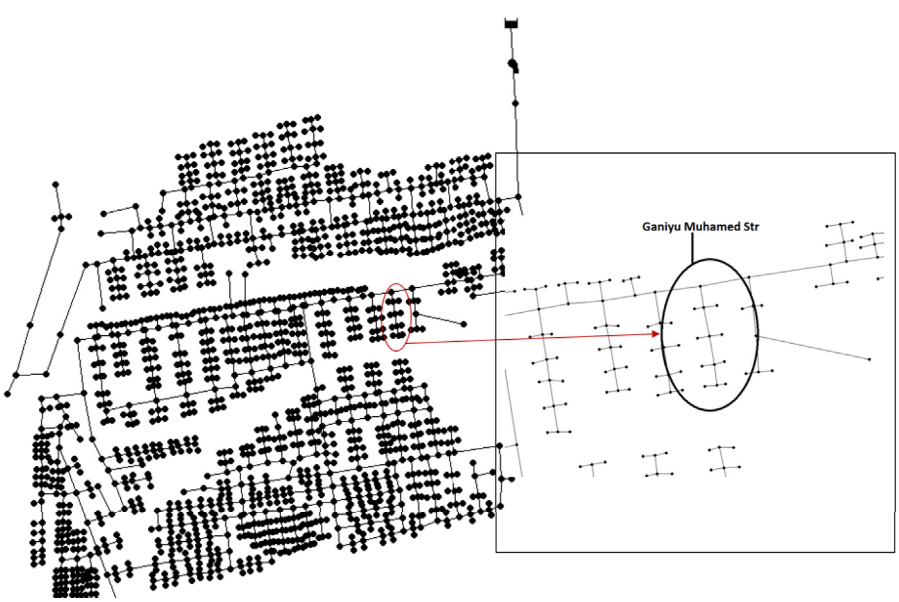


Fig. 13. GaniyuMuhammed Crescent.

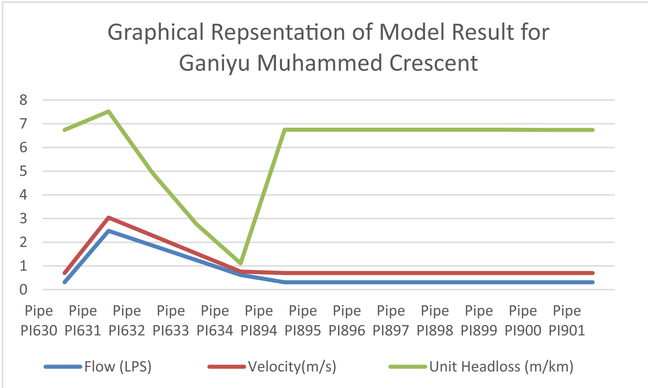


**Fig. 14.** Graphical representation of model result for GaniyuMuhammed Crescent.

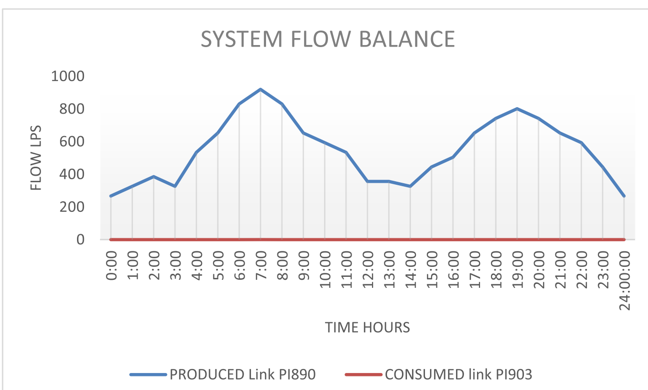


**Fig. 15.** System flow balance.

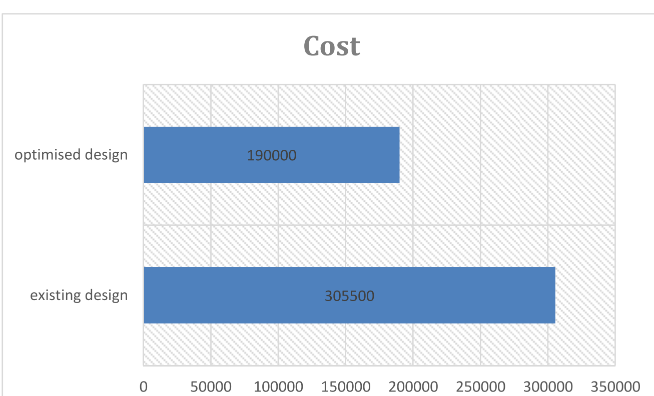


**Fig. 16.** Cost minimization.

solution. The model representation of the existing water distribution system was solved by using initial pipe diameters of 150, 200, 250, 300 and 400 mm size, the pressure generating elevation of 25, 30 and 35 m head characteristics. The problem evaluates seamlessly and the total run time was 0.23 s. Results showed that the optimum reservoir height is 25 m while the optimum pipe diameter was determined to be 300 mm and consequently a 38% reduction in total cost of installation, operation and maintenance of the water distribution system (WDS).

## 5. Recommendation

This research carried out the cost and hydraulic design optimization for the water distribution system case study and further studies in other areas of the water distribution system are pending and should be researched on. Some of these areas include.

- valve location and reservoir optimization; thorough research should be done in this areas to further reduce water losses and inefficiency in water distribution systems
- Also, design firms should begin to use simulation, modeling and optimization software in the design of mechanical services for estate development and buildings rather than depending on static design standards which increasingly becoming unreliable due to their inability to meet or satisfy demand.

In the design of a water distribution system a lot of complexities exist, mainly because of the relationship between non - linear head loss and discrete nature of pipe sizes. However, the lowest cost design of WDS has always been the focus of research due to its enormous costs. Furthermore, a test and errors approach remains the best allocation of available water to the demands of service reservoirs.

## CRediT authorship contribution statement

**O.M. Awe:** Conceptualization, Methodology, Software, Data curation, Writing - original draft. **S.T.A. Okolie:** Visualization, Investigation, Supervision. **O.S.I. Fayomi:** Conceptualization, Methodology, Validation, Writing - review & editing.

## Acknowledgements

The authors are grateful to Covenant University and department of Mechanical Engineering, Covenant University for the support granted during the development of this work.

## References

[1] L. Guppy, P. Uyttendaele, K.G. Villholth, V. Smakhtin, Groundwater and Sustainable Development Goals: Analysis of Interlinkages, UNU-INWEH Report Series, 2018. Issue 04.
[2] H. Mala-Jetmarova, N. Sultanova, D. Savic, Lost in optimisation of water distribution systems? A literature review of system operation, Environ. Model. Software 93 (2017) 209–254.
[3] G. Tsakiris, Rational design of urban water supply and distribution systems, Water Util J 8 (2014) 5–16.
[4] D. Savić, H. Mala-jetmarova, N. Sultanova, History of Optimization in Water Distribution System Analysis, 2018.
[5] O.S.I. Fayomi, D.O. Olukanni, G.U. Fayomi, O.O. Joseph, In situ assessment of degradable carbon effusion for industrial waste water treatment, Cogent Engineering 2017 (4) (2017) 1291151, https://doi.org/10.1080/23311916.2017.1291151.
[6] E.O. Longe, D.O. Omole, I.K. Adewumi, S.A. Ogbiye, Water resources use, abuse and regulations in Nigeria, J. Sustain. Dev. Afr. 12 (2) (2010) 35–45.
[7] L. Ramulongo, N.S. Nethengwe, A. Musyoki, The nature of urban household water demand and consumption in makhado local municipality: a case study of makhado newtown, Procedia Enviro. Sci. 37 (2017) 182–194.
[8] H.M. Samani, A. Mottaghi, Optimization of water distribution networks using integer linear programming, J. Hydraul. Eng. 132 (5) (2006) 501–509.
[9] B.S. Jung, B.W. Karney, P.F. Boulos, D.J. Wood, The need for comprehen-sive transient analysis of distribution systems, J. American Water Works Associa-tion 99 (1) (2007) 112–123.
[10] J. Lavaei, S.H. Low, Zero duality gap in optimal power flow problem, IEEE Trans. Power Syst. 27 (1) (2012) 92–107.
[11] Y. Lin, L. Schrage, The global solver in the LINDO API, Optimisation Methods and Software 24 (4–5) (2009) 657–668.
[12] UN-Water, Sustainable Development Goal 6 Synthesis Report on Water and Sanitation, UN-Water, Geneva, 2018.

## Update

# Results in Engineering

Volume 8, Issue , December 2020, Page

DOI: https://doi.org/10.1016/j.rineng.2020.100180

Results in Engineering 8 (2020) 100180

Contents lists available at ScienceDirect

Results in Engineering

journal homepage: www.editorialmanager.com/rineng/Default.aspx

# Erratum regarding missing Declaration of Competing Interest statements in previously published articles

Declaration of Competing Interest statements were not included in the published version of the following articles that appeared in previous volumes of *Results in Engineering*.

The appropriate Declaration/Competing Interest statements, provided by the Authors, are included below.

**"Simultaneous removal of organics and metals in fixed bed using gravel and iron oxide coated gravel" Results in Engineering, 5(2020),** https://doi.org/10.1016/j.rineng.2019.100093.

"The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper."

**"Suppression of photothermal convection using silicon carbide substrates for optofluidics experiments" Results in Engineering, 5(2020),** https://doi.org/10.1016/j.rineng.2020.100097.

"The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper."

**"Low turn-on voltage of doped organic light emitting diodes based on food dyes" Results in Engineering, 5(2020),** https://doi.org/10.1016/j.rineng.2020.100099.

"The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper."

**"Analysis and optimization of water distribution systems: A case study of Kurudu post service housing estate, Abuja, Nigeria" Results in Engineering, 5(2020),** https://doi.org/10.1016/j.rineng.2020.100100.

"The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper."

**"Effect of standoff distance on the kerf characteristic during abrasive water jet machining" Results in Engineering, 6(2020),** https://doi.org/10.1016/j.rineng.2020.100101.

"The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper."

**"Qualitatively-improved identified parameters of prestressed concrete catenary poles using sensitivity-based Bayesian approach" Results in Engineering, 6(2020),** https://doi.org/10.1016/j.rineng.2020.100104.

"The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper."

**"Performance of mechanical agitation type of ground-improvement by CAE system using 3-D DEM" Results in Engineering, 6(2020),** https://doi.org/10.1016/j.rineng.2020.100108.

"The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper."

**"Automatic generation of truck configurations for bridge load ratings in the state of North Carolina" Results in Engineering, 6(2020),** https://doi.org/10.1016/j.rineng.2020.100115.

"The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper."

**"Experimental investigation of heat transfer characteristics and performance of smooth and wicking surfaces in spray cooling for high heat flux applications" Results in Engineering, 6(2020),** https://doi.org/10.1016/j.rineng.2020.100119.

"The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper."

DOIs of original article: https://doi.org/10.1016/j.rineng.2020.100100, https://doi.org/10.1016/j.rineng.2020.100115, https://doi.org/10.1016/j.rineng.2020.100119, https://doi.org/10.1016/j.rineng.2019.100093, https://doi.org/10.1016/j.rineng.2020.100101, https://doi.org/10.1016/j.rineng.2020.100099, https://doi.org/10.1016/j.rineng.2020.100097, https://doi.org/10.1016/j.rineng.2020.100104, https://doi.org/10.1016/j.rineng.2020.100108, https://doi.org/10.1016/j.rineng.2020.100100, https://doi.org/10.1016/j.rineng.2020.100115, https://doi.org/10.1016/j.rineng.2020.100119, https://doi.org/10.1016/j.rineng.2019.100093, https://doi.org/10.1016/j.rineng.2020.100101, https://doi.org/10.1016/j.rineng.2020.100099, https://doi.org/10.1016/j.rineng.2020.100097, https://doi.org/10.1016/j.rineng.2020.100104, https://doi.org/10.1016/j.rineng.2020.100108.

https://doi.org/10.1016/j.rineng.2020.100180