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Optimization Model for Potable Water supply in Ladoke Akintola University of Technology Main Campus, Ogbomoso Oyo State, South-Western Nigeria

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Abstract

The demand for water supply in Ladoke Akintola University of Technology (LAUTECH), Ogbomoso is increasing due to population growth. In this study, an optimization model was developed to manage present and future demand for portable water supply in LAUTECH. A reconnaissance survey for water source was carried out from January to March 2018.Population of the students and staffs were obtained from Registry. Two hundred (200) questionnaires were distributed to various University staff to determine their water usage. The daily water demand from 2016 to 2046 was estimated using geometrical progression method. Yield of boreholes and wells were determined using recuperation method. New pipe network of the University was generated using Remote sensing data. Existing pipe networks in the University were used to determine Pipe discharge, velocity, pressure and diameter. Objective functions were formulated to optimize the pipe diameter and cost. There are twenty-two (22) boreholes in LAUTECH and only eleven (11) are functioning. The estimated total daily consumption for 2016 and 2046 were 1602.00 and 2043.40 m3/day, respectively. The yield of boreholes and wells were 1.331 l/s and 0.376 l/s, respectively. The estimated pipe discharge, velocity, pressure and diameter were 0.01 m3/s, 1.50 m/s, 1200 kN/m2 and 75 mm, respectively. Linear results produced 37 and 63% of 100 and 75mm diameter pipes respectively, equivalent to 16,389m pipe at a minimum cost of N54, 677, 450. The developed model can serve as baseline information for efficient water resources management in the University..

Keywords

Optimization; Modeling; Portable Water; and MATLAB.

1.0 Introduction

Water is vital for human existence. Without water, there is no life. Municipal water supply systems constitute a central part of the public infrastructure. Water supply facilities are usually sized with sufficient capacity to meet anticipated flows in the future. The amount of excess capacity depends on economies of scale and the time value of money. On the one hand, economies of scale make it attractive to build beyond immediate needs, as incremental costs are often small. On the other hand, decision-makers will tend to postpone investments in facilities that remain unproductive for long periods, as this can result in considerable savings in the present value of total investment costs (Cai et al., 2001 & Ejeta et al., 2004). Costs of water facilities are very difficult to estimate and the use of inappropriate cost functions may bring inaccuracy to hydraulic network models (Cai et al., 2001).This can be achieved by using an optimization technique rather than the traditional trial-and-error method (Price and Ostfeld, 2013 & Geem et al, 2002).

Optimization techniques produce best results; attain the highest profits, output, or happiness; or achieve the lowest cost, waste, or discomfort. Often these problems involve making the most efficient use of your resources, which include money, time, machinery, staff, and inventory among others. Optimization problems can be linear or nonlinear, depending on whether the relationships in the problem are linear with respect to the variables (Xiongfei, 2014 & Jens et al, 2004). Linear Program (LP) can express optimization problems. The problem of Mixed-Integer Linear Programs (MILP) is an extension of LPs where some of the decision variables are required to take integer values. Objective function in LPs may be nonlinear such as logarithms, such problems are Nonlinear Programs (NLPs). A special case of NLPs is Quadratic Programs (QPs) where the only nonlinear relationships among variables are products of two variables. Integrity restrictions on some variables are expressed in Mixed-Integer Nonlinear Programs (MINLP) or Mixed-Integer Quadratic Programs (MIQP), respectively (Xiongfei, 2014).

Stochastic optimization methods are used in water supply system design to deal with supply and demand uncertainties. Most existing work focused on two-stage and/or multistage linear or nonlinear stochastic programming. The objectives in design were to minimize total cost for the water transfers, develop long-term and short-term management options, manage supply capacity and develop operation protocols for water shortage management (Muhamed and Al-Muala, 2010). The applications optimized the system with respect to the expected values of the objective function but did not consider risk-averse behaviour or trade-offs between sub-optimality and infeasibility. Despite the consideration of constraint penalty functions in these expected valued optimizations, decisions that hedge against risk were considered in few researches (Jenkins and Lund, 2000).

Bertsimas and Sim (2004) presented a framework to find robust solutions that are not affected by data uncertainty as applied in a water supply system. This paradigm in robust optimization was introduced but the solutions are too conservative in a sense that much of optimality is lost for the system robustness. A conservative design usually leads to a high-cost, which might not be desirable in practice. Ben-Tal and Nemirovski (2000), considered uncertain linear problems with ellipsoidal uncertainties and proposed a new approach for robust optimization in order to overcome the conservatism. In order to control the conservatism, these approaches introduced nonlinear problems into the system, which are computationally intractable. This difficulty motivated Bertsimas and Sim (2004) to suggest another approach for robust optimization.

Hydraulic network models can be represented by mass-balance, regression, simplified hydraulic and full hydraulic model. In mass-balance model, the flow rate within the system is determined by the demand for water plus the rate of variation in water levels in the reservoirs. The pressure requirements for obtaining the flow of water in the reservoirs are neglected and it is assumed that, to obtain the desired water volume in the reservoirs, a combination of pumps are available (Ikonen et al., 2012). Furthermore, if the water level in the reservoirs remains within a previously specified range, the pressure requirements on the nodes of the network will be omitted (Toledo et. al., 2008). Such models incorporate important functional relations between the level of water in the reservoirs and the pumped flow. Hydraulic characteristics of the network in mass balance models are only determined using water balance restrictions in the reservoirs, the multi-dimensional mass balance model are converted into linear optimization programs. Thus, the main advantage of mass-balance models is the relative tractability of the corresponding optimization problem (Soler, 2008 & Ikonen et al., 2012).

Ogbomoso lies approximately, on latitude 8˚10' North of the equator and longitude 4˚10' E of the Greenwich Meridian. The region has five local governments namely:Ogbomoso South, Ogbomoso North, Orire, Ogo-Oluwa and Surulere. It is situated in the Southern Guinea Savannah zone and dominated by Yoruba ethnic group. Majority of Ogbomoso residents depend solely on groundwater (well and boreholes) for their potable water supply. More than 33% of the public boreholes in the University are in a state of disrepair and not functioning as expected (Toyobo, 2014).

Ladoke Akintola University of Technology (LAUTECH) main campus is located in Ogbomoso North Local Government Area. The University has seven (7) faculties, which includes Agricultural Sciences, Environmental Sciences, Engineering and Technology, Pure and Applied Sciences, Management Sciences and College of Health Sciences. Presently, the University has 32,000 students and nearly four thousand administrative staff. LAUTECH community depends solely on groundwater and water vendors. Several attempts were made by the university community to improve on the quantity of portable water generated such as provision of more boreholes and wells, collaborating with Oyo State Water Corporation and procuring water from water vendors. However, the demand is still greater than the supply (Adewumi, 2019).

However, providing sufficient water of appropriate quality and quantity has been one of the most important issues in the University. As populations grew, the challenge to meet user demands also increased. Construction of new toilet facilities in strategic location to stem indiscriminate defecation on campus, expanding laboratories and commissioning of new structures have put pressure on existing water supply services. Presently, out of twenty-two (22) boreholes and seven (7) shallow wells in the University, only eleven (11) boreholes and three (3) shallow wells are functioning. It is on record that LAUTECH provides about 403,500 litres of water out of the estimated the 1,602,000 litres daily water demand which is equivalent to about one-quarter of the daily water demand. In view of the forgoing, the only way to rescue the unfortunate situation is to improve on the available quantity of water and judiciously manage the water consumption pattern (Adewumi, 2019).

This study assesses existing water supply facilities in LAUTECH, compute present and future (projected design Year - 2046) water demands, develop an appropriate objective function for optimized water model.

2.0 Materials and Methods

Reconnaissance survey of LAUTECH community was carried out to determine the location of various boreholes and wells using Geographic Information System (GIS). The respective conditions and their yield of wells and borehole were determined through recuperating test. LAUTECH population was obtained from Registry Department and daily water demand for the present year (2016) was computed using information obtained from two-hundred (200) sample questionnaires administer to University staff. Water demand for projected year (2046) was determined using geometric progression method. A new pipe layout was generated using location map and GIS. Remote sensing satellite imagery was acquired from Goggle earth to identify the water pipeline network in the study area. The water pipeline network was extracted from the GIS environment using vectorization method. Coordinate location of the area was also acquired with GPS. The ground truth method was done using purposive sampling method to ensure that all possible pipelines were sampled by picking their coordinates. These coordinates were plotted and overlay on the extracted pipelines in the GIS environment to distinguish various pipe diameter types and various area of connection as presented in Figure 1. Pipe parameters were calculated using continuity and Darcy-Weisbach equations. The obtained information was converted to equations and was optimized using Matlab software.

The mathematics expressions of model descriptions were generated from information obtained from LAUTECH piping network to minimize water supply and distribution cost in LAUTECH, main campus. Variables were identified which includes length, discharge, pressure, diameter and velocity. Constraints of each variable and constraints governing each equation were determined. The controllable variables (cost, length, discharge and pressure) were determined and specified in mathematical notation. The obtained expressions were converted into optimization toolbox solver syntax. Objective function was formulated to minimize cost, and the variables were converted into vector. Linprog defines a set of lower and upper bound on design variables. Linprog was chosen as most appropriate solver in this study. The bound and linear inequality constraints were written, linprog was used to solve the problem, and the result was validated.

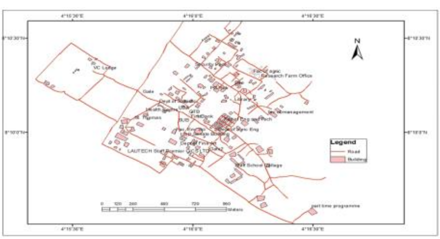

Figure 1. LAUTECH Piping Network

3.0 Results and Discussion

Location of various boreholes at LAUTECH and their condition is presented in **Table 1.** The yield of boreholes and wells in the University were determined from recuperating test. The LAUTECH population for the present and future year along with water demand is shown in **Table 2.** The piping network in LAUTECH with contours of various points from which constrains equations and objective function were formulated is presented in **Figure 2.**

Table 2: Description of Borehole Points and Condition in LAUTECH

S/N	Location	Longitude/Latitude	Condition
1	Health Center	8°10′12″N/4°15′48″E	F
2	Engineering Workshop	8°09′50″N/4°16′10″E	F
3	S.U.B	8°10′05″N/4°16′00″E	F
4	Senate Building	8°10′04″N/4°15′05″E	F
5	Botanic Garden	8°09′05″N/4°16′25″E	NF
6	Library	8°10′10″N/4°16′08″E	NF
7	100 Level Laboratory	8°10′09″N/4°16′04″E	NF
8	Old Works Department	8°10′05″N/4°15′07″E	F
9	Old Management	8°10′02″N/4°16′04″E	NF
10	New Management	8°10′05″N/4°16′15″E	F
11	New I.C.T	8°10′04″N/4°16′13″E	F
12	Guest House	8°10′15″N/4°15′26″E	NF
13	V.C'S Lodge	8°10′25″N/4°15′35″E	F
14	FAGS (FAC. of Agric. Building)	8°10′15″N/4°16′12″E	F
15	Skye Bank	8°10′07″N/4°16′00″E	F
16	GT Bank	8°10′05″N/4°16′02″E	F
17	First Bank	8°10′04″N/4°16′01″E	NF
18	Engineering Building	8°10′03″N/4°16′06″E	NF
19	FAGS (FAC. of Agric. Building II)	8°10′16″N/4°16′10″E	NF
20	New Laboratory Complex	8°10′12″N/4°16′08″E	NF
21	New Laboratory Complex II	8°10′13″N/4°16′10″E	NF
22	Old Physics & Chemistry Laboratory Complex	8°10′15″N/4°16′02″E	NF

Table 2: LAUTECH Daily Water Demand for the Current year and Ultimate year

Session	Population	Water Demand (Litres/day)
2015/16	29,420	1,602,000
2045/46	35,930	2,043,400

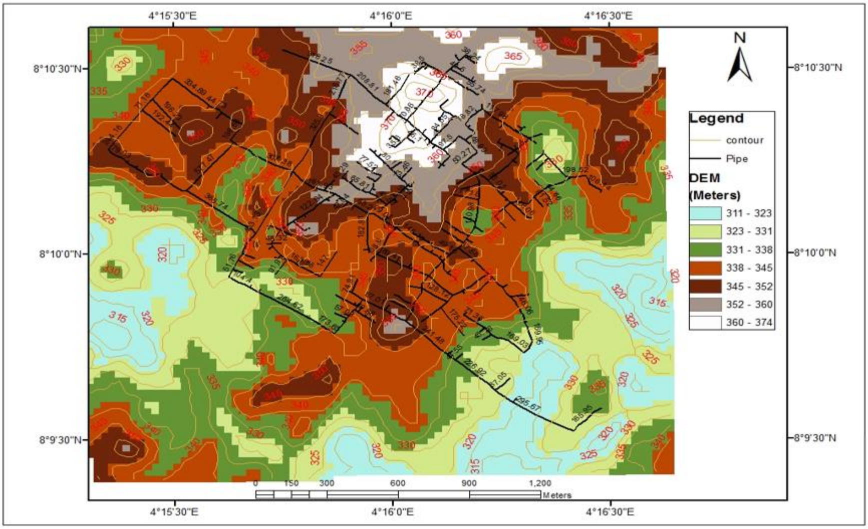

Figure 2. *LAUTECH Piping Network and Contour*

3.1 Numerical Application

The known data in this study includes pipes length (L) in m, elevation head (*Z)* in m, and necessary pressure (*H)* = 24 m H_2O. A comparative study of network dimensioning was performed using the classic model of average economical velocities (MVE) and the linear optimization model developed.

The objective function of the optimization is shown in Equation 1

$$C = 6500x + 8600y \qquad 1$$

Where:

$c = overall\ cost\ (\ Nairax = Number\ of\ 75mm\ diameter\ pipe$

$y = Number\ of\ 100mm\ pipe$

The laboratorThe constraint inequalities in this study are presented in equations 2 – 4. They are specified by the limits on discharge, length of pipe and pressure in the pipe. They are:

$4.51x + 78.33y \leq 797.86$ [discharge(m^3/s)] 2

$3.60x + 3.30y \leq 26015$ [length (m)] 3

$x + y \leq 62000.4$ [pressure (N/mm^2)] 4

$$0 \leq x \; and \; 0 \leq y \;\; all \; pipes \; lenght \; must \; be \; positive$$

To solve this problem, a linear programming problem, which minimizes a function f(x) subject to some constraints, was used. A proxy function to negate cost, which was intended to minimize cost, was created as shown in equation 5. Equations (6-9) were generated for the optimization process.

$f = 6500x - 8600y$ 5

$\{-6500|-8600\}$

Where: f = Inequality constraints

The constraints is in the form $A\,x \leq b$

$4.51x + 78.33y \leq 797.86 \;\; 3.60x + 3.30y \leq 26015x + y \leq 6200$ 6

$120x + 210y \leq 15000 \;\; 110x + 30y \leq 4000 \; x + y \leq 75$ 7

$$A = \begin{matrix} 4.51 & 78.33 \\ 3.60 & 3.30 \\ 1 & 1 \end{matrix}$$ 8

$b = \{797.86|26015 \; 62000\}$ 9

Lower bounds

Finally, the lower bounds on the unknowns were expressed as $0 \leq x \; and \; 0 \leq y$

lb = 0 0 { }

Few results of hydraulic characteristics of the pipes are shown in **Table 3.**

However, Fifty percent of boreholes at LAUTECH are not functioning. By 2046, LAUTECH population and water demand will increase by 22 and 28%, respectively. Average yield of boreholes and wells were 1.331 l/s and 0.376 l/s, respectively as shown in **Table 4.** The overall length of piping network was 26015 m. The contour in LAUTECH main campus varied from 311-374 m. The design discharge, velocities and pipe diameters were 0.104 m^3/s, (1.5 - 1.8) m/s and (75 – 100) mm, respectively. The optimum result revealed that 37% of 100mm diameter pipe will be required, which was equivalent to 9,626m and 63% of 75mm diameter pipe equivalent to 16,389m, at minimum cost of ₦54, 677,450.

Table 3: Hydraulic Characteristic of the Pipes

Pipe Number	Length (m)	Diameter (mm)	Velocity (m/s)	Discharge (m^3/s)	Head Loss h_f (m)
1	19.17	75	1.5	0.01	0.115
2	24.83	100	1.5	0.01	0.1117
3	17.18	100	1.5	0.01	0.0773
4	106.14	100	1.5	0.01	0.6368
5	132.65	100	1.5	0.01	0.5969
6	116.29	100	1.5	0.01	0.5233
7	111.59	100	1.5	0.01	0.5022
8	69.32	100	1.5	0.01	0.3119
9	146.06	100	1.5	0.01	0.6573
10	83.3	100	1.5	0.01	0.4998
11	94.12	100	1.5	0.01	0.4235
12	45.81	100	1.5	0.01	0.2749
13	53.39	100	1.5	0.01	0.3203
14	66.9	100	1.5	0.01	0.4014

Table 4: Yield of LAUTECH Boreholes and Wells

Sources	**Daily Water Produced (m^3/day)**	**Yield (L/s)**
Borehole	19.50-39.00	0.856-1.805
Well	3.75-4.50	0.335-0.417

4.0 Conclusion and Recommendation

The existing water supply in LAUTECH community is 403,500Litre/day. The existing (2015/16) water and future (2046) water demand are 1,602,000 and 2,043,400 Litres/day. The developed objective function for optimal water model on LAUTECH was C= 6500x + 8600y and constraint were 4.51x + 78.33y <= 797.86 (discharge), 3.60x + 3.30y <=26015 (length) and x + y<= 62000 (pressure).

LAUTECH should collaborate with government and non-governmental organizations in order to augment the amount of water generated. Regular and routine maintenance should be carried out on boreholes, wells, pipes and their storage facilities. In order not to deplete underground water, LAUCTECH should consider construction of mini dam.

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