An Extended Period Analysis of the Water Pipe Network System in Calabar

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Abstract

Calabar as the capital of Cross-river is the most populated city in the state. The present water distribution system, Cross River State Water Board Ltd(CRSWBL) serves an increasing population of over 605,000 persons and more(according to NPC, 2021) posing an increasing water demand. However, there has been no significant improvement made to the water distribution network. An extended period simulation was performed on the CRSWBL distribution network to evaluate its performance with respect to hydraulic head loss, velocity, pressure and nodal demands at different times of the day using WaterCAD and Epanet. According to universal standards, a flow rate with a minimum of 0.15litrepersecond (LPS) as well as a pressure head with a minimum of 15m and maximum of 70m were used as yardsticks. Areas with flow rates and pressure heads that fell short of these standards were noted. Both software used, WaterCAD and Epanet produced nearly the same outputs with statistically negligible differences. At the end of the study, it was concluded that the performance of the pipe distribution network in Calabar under the current water demand is slightly inefficient in some areas and appropriate approaches were recommended.

Keywords
Water, Demand, Velocity, Pressure, EPANET

1. Introduction
Water Distribution Networks (WDNs) form the connection between the waterworks and distribution system. It provides a variety of functions in addition to providing water for human consumption. Piped water is also used for washing, sanitation, irrigation, industrial usage, and firefighting. Pipe network analysis is an important aspect of distribution systems which are complicated systems consisting of several pumps, reservoirs, valves of different kinds, and other appurtenances (Agunwamba 2000).

The objective of a pipe system is to supply water at an optimum pressure and flow, and networks are constructed to meet peak requirements. However, the pressure loss is further affected by the amount of water used, the length of the pipe, the gradient, and the diameter of the pipe. The water demand, pipe length, gradient, and diameter all affect pressure loss. The pressure-flow relationship is described by a number of proven empirical equations, which have been included into network modeling software programs to make their solution and use easier (Weber, 1971). Water utilities' primary function is to distribute the needed amount of water to individual consumers under sufficient pressure via a distribution network..

Water is only available for a few hours each day in most Nigerian cities, the pressure is inconsistent, and the water is of poor quality. Intermittent water supply, insufficient pressure, and unpredictable service impose both financial and health costs on Nigerian households. Computer-based commercial water distribution system models such as EPANET, Water CAD, Water NET, and Water GEMS were introduced to analyze these pipe networks as well as water distribution systems.

These fast-growing technologies have induced real-time computer simulation modeling of water networks, such as the Epanet 2.0 software designed by the Water Supply and Water Resources Division of the United States Environmental Protection Agency which is used in this study. This tool becomes handy for the planning of pipe network systems to meet present and forecasted water demands as well as to manage the operation status of the system (Rossman 2000).

However, advances in application development now promote the integration of models that reflect both single-period and extended-period network research. The distribution system must function properly to provide an acceptable level of service to consumers under different situations of demand and reservoir water levels. From an operational point of view, it is necessary to adequately maintain the flow rates and pressures at all nodes at various times; it is also necessary to manage the storage to balance the supply and distribution. These objectives can be achieved by carrying out the analysis of the network over a period of 24-48 hours under varying nodal demands and reservoir water levels.

The issue of water stress due to population growth and other factors is not new and has been in the fore-front of academic discussion. Rapid population increase in a country, especially in the developing climes, is a threat to the environment through strong demand for water consumption. Because of the challenges with inequitable access to pipe-borne water delivery in Calabar, this methodology becomes necessary. According to the Water Project Report (2014), 783 million people lack access to clean, safe water, with 37 percent of this population living in Sub-Saharan Africa (UN 2021). The United Nations Sustainable Development Goals 6 were influenced by this (UNSDGs). By 2030, the sixth Sustainable Development Goal (SDG) will have been achieved: universal and equitable access to safe and affordable water (UN 2021). Water collection, treatment, and distribution have long been the responsibility of State Water Boards (SWBs) Agencies or Corporations in Nigeria. In Calabar metropolis, the provision of pipe-borne water has been tasked to the CRSWBL since 1998 which was earlier established as Water Board, by edict No. 13 of 1975 (Njoku et al. 2017). Its major functions were to establish, control, manage and develop new waterworks and to extend, manage and develop existing ones for the purpose of providing water for individual and domestic needs (CRSWBL 2021). In 2015, CRSWBL recorded an average monthly water supply of 573,981 m3. The supply rate has gradually increased since the inception of the water board service wherein 2007 the average monthly supply was 360,738 m3 (CRSTU 2021). CRSWBL delivers processed water from their treatment facility at Ndidem Isong Road, Calabar, through a series of pipelines. The water is pumped from the ground level reservoirs (GLRs) into the elevated water tanks (EWTs) from where it is fed to homes by gravity.

Therefore the focus of this study is to use EPANET in the Extended Time Analysis of the water pipe network system in Calabar. This is done with a particular focus on determining the optimum demand, discharges in pipes and pressures at junctions (Abubakar and Sagar 2013).

1.1 Objectives

The aim of this project is to conduct an extended time analysis of the water pipe network system in Calabar using EPANET.

The objectives of the project are as follows:

i. Using Epanet and WaterCad programs to perform real-time simulation of hydraulic and water quality behavior within pressurized pipe networks.
ii. Simulate daily water use, analyze the pressure variations at each node, and track the flow of water in each pipe.

2. Literature Review

This chapter reviews the literature relevant to the objectives of the study, which consist of discussing the requirements of analyzing a water pipe network over a period of time under varying nodal demands for optimal distribution as well as data on water use characteristics.

A well-designed water system is meant to operate optimally such that consumers have access to potable water of sufficient pressure and quality at all times (Bwire 2015). In addition to providing water for human consumption, which accounts for less than 2% of the total volume provided, water distribution networks serve a variety of other functions (Darshan et al. 2016). They opined that the purpose of a system of pipes is to supply water at adequate pressure and flow and these networks are designed to meet peak and ever increasing demands. However, low flow conditions can be detected in parts of the network, loss of pressure can also be detected due to the action of friction at the pipe walls. This pressure loss is dependent on the water demand, pipe length, gradient and diameter.

Maidugri has a water supply scheme which divides the town into five water supply distribution zones. Alkali et al. (2017) decided to research on Zone 3, which is one of the three remaining zones in the city without a distribution network which should get supplies from the Maidugri water treatment plant. Using the Epanet software, the aim was to provide effective planning, development and optimum operation of the proposed water supply network. The study used data provided by the municipality to delineate the topography of the area, population of people, water demand and climate conditions. The pipe borne water network of the area was analyzed for a 24 hour supply having a demand approximately equivalent to 420 litres per second (LPS). The pipes conveying water into the system and for distribution were designed with all primary pipes having diameters of 300m while pipes supplying water from the reservoirs into the distribution network have higher diameters of 400m. Three gravity water reservoirs were proposed to supply water to the zone to cater for comfortable flow rate and pressure though out the system. Recommendations were made on practical ways to balance distribution for intermittent supply through maintaining an economical approach of 7 hours water supply to limit cost for constructing overhead tanks and residents advised to have personal reservoirs to cater for the remaining 17 hours without water supply.

Furthermore, Agunwamba et al. (2018) evaluated the performance of Wadata sub-zone water distribution system by comparing the result of the pressure, velocity, hydraulic head loss and nodal demands of the distribution system between WaterCAD and Epanet. The pipe network analysis was carried out and the results obtained from the simulation of the network using both models showed that the nodal pressures and velocities of both WaterCAD and Epanet were almost identical. However, it was seen that Epanet produced slightly higher results of pressure and velocity in about 60%of all cases examined. The review of this study showed lapses in the water distribution in Wadata sub-zone due to velocities exceeding the adopted velocity causing leakages and pipe burst within the network system thereby rendering the water distribution performance as inefficient under its current demand.

3. Methods

Calabar is the capital city of Cross River State in southern Nigeria. It lies between longitudes 08°19’30’’E to 8°24’00’’E of the Greenwich meridian and latitudes 04°57’00’’N to 5°04’00’’N of the equator. The metropolis covers a land area of 406 square kilometers (sqkm) and an estimated population of 605,000 in 2021 with a 4% growth rate.
The main water supply sources of the Calabar Metropolis are the Great Kwa River on the east and the Calabar River on the west of the city.

Calabar is situated on a gently sloping plain with mean sea levels varying from 85 (Ikot Effanga) to 09 (Eta Agbor).

The water is pumped from the river bank to the treatment facility where it is being treated through several treatment processes. The pipe-borne water distribution area is delineated into 4 main zones; Ikot Effanga, Ediba Qua, Diamond Hill and Eta Agbor distribution zones (Figure 1). Each zone has its elevated water tank where the water is distributed under gravity through a network of pipes and junctions. The pipes range in size from 600mm diameter pipes that transport water from tanks to 75mm pipes and eventually service lines that distribute water to homes.

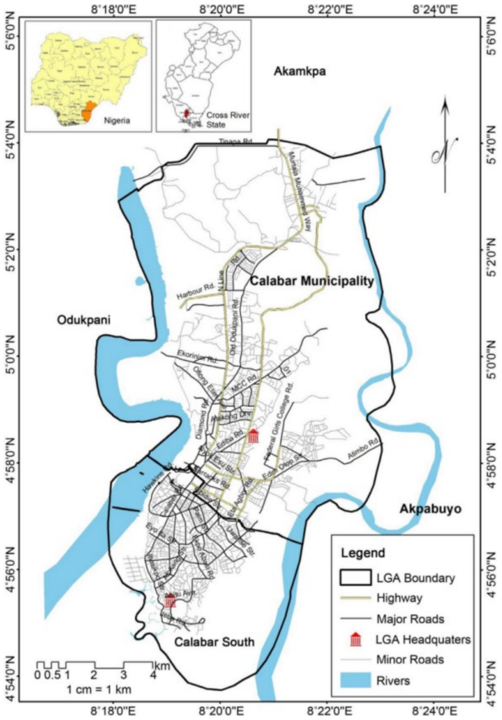

Figure 1. Map of Calabar Metropolis (Calabar south and municipality LGAs)
Source: Office of the surveyor general, cross river, 2020.

The administrative map showing the location of the municipal with geo-reference coordinates obtained from the office of the surveyor general, cross river, is as shown in figure 1 above. The study area (calabar municipality and calabar south) acts as a stand-alone municipality providing its own water, waste-water collection and treatment (Figure 2).

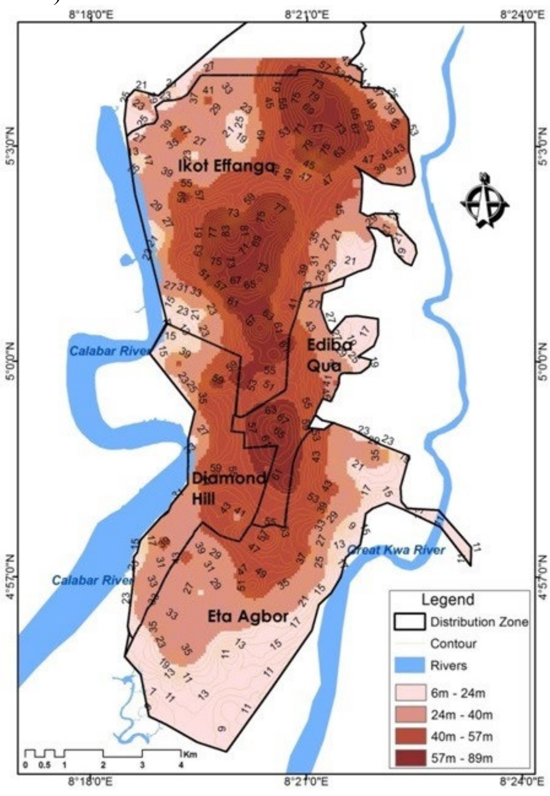

Figure 2. Topography of Calabar metropolis and the four distribution zones
(Source: Onah Okon, C. G.Njoku, 2016)

3.1 Procedures For Modelling A Water Distribution Network Using Epanet

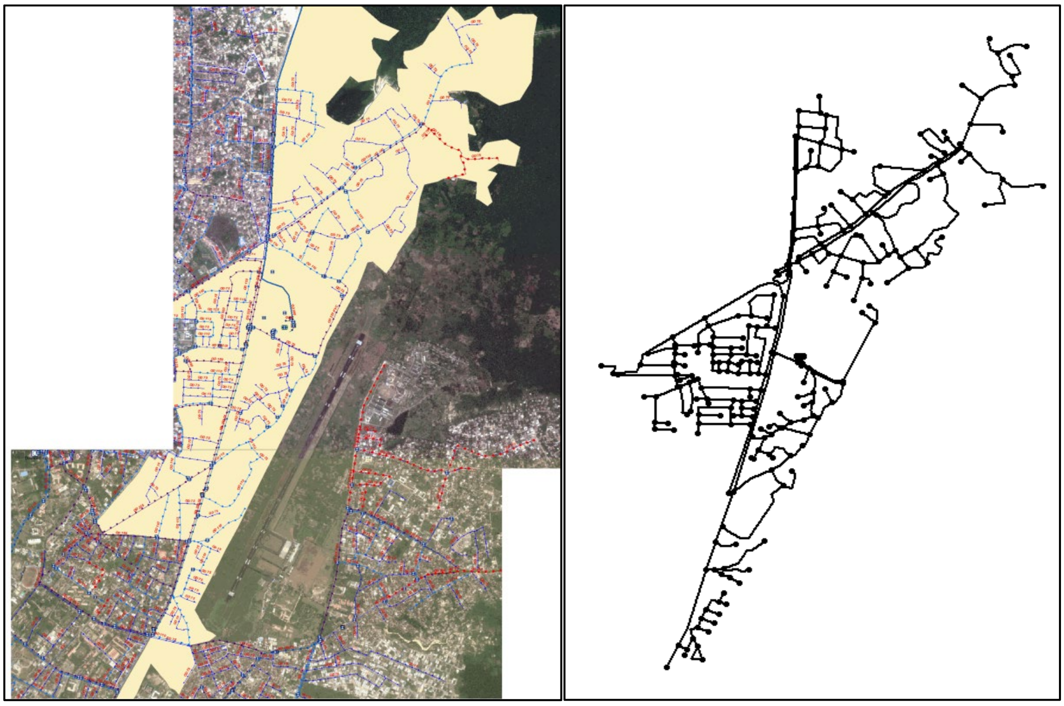

Figure 3. Topography of Ediba Qua Metropolis and Similar Network Drawn on Epanet

The following are the steps carried out to model water distribution network (Figure 3).
Step1: Draw a network representation of distribution system or import a basic description of the network placed in the text file (Figure 4).

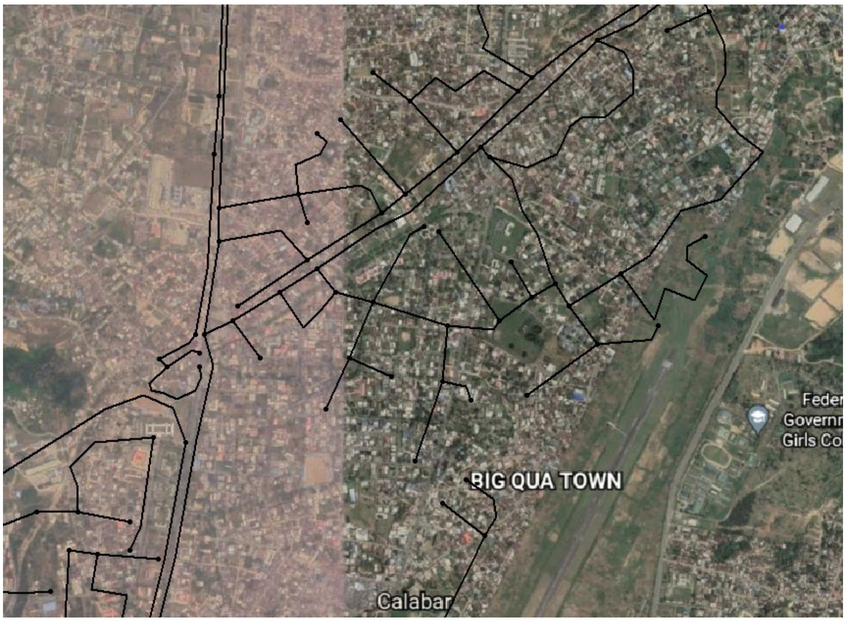

Figure 4. Superimposing the Epanet Network on the Backdrop

Step 2: Edit the properties of the elements that make up the system (Figure 5). It includes editing the properties and entering required data of various objects like tanks, pipes, junctions etc.

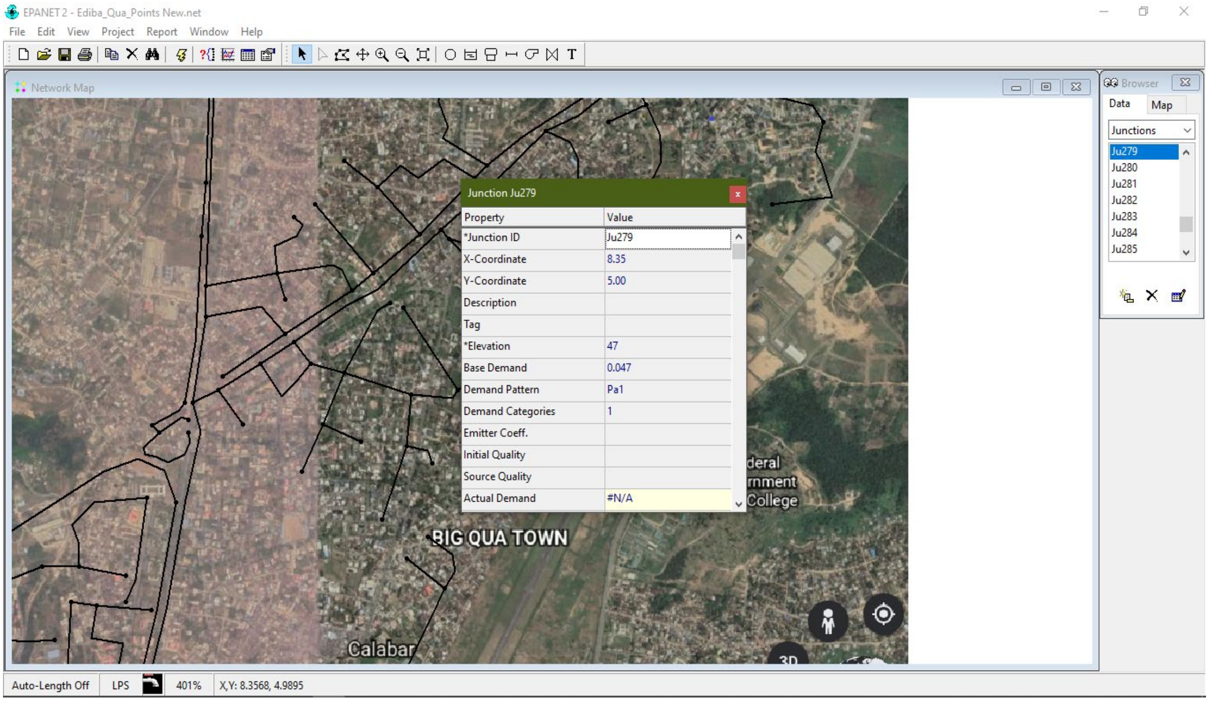

Figure 5. Property Editor

Step 3: Describe how the system functions by imputing the demand pattern of the network (Figure 6).

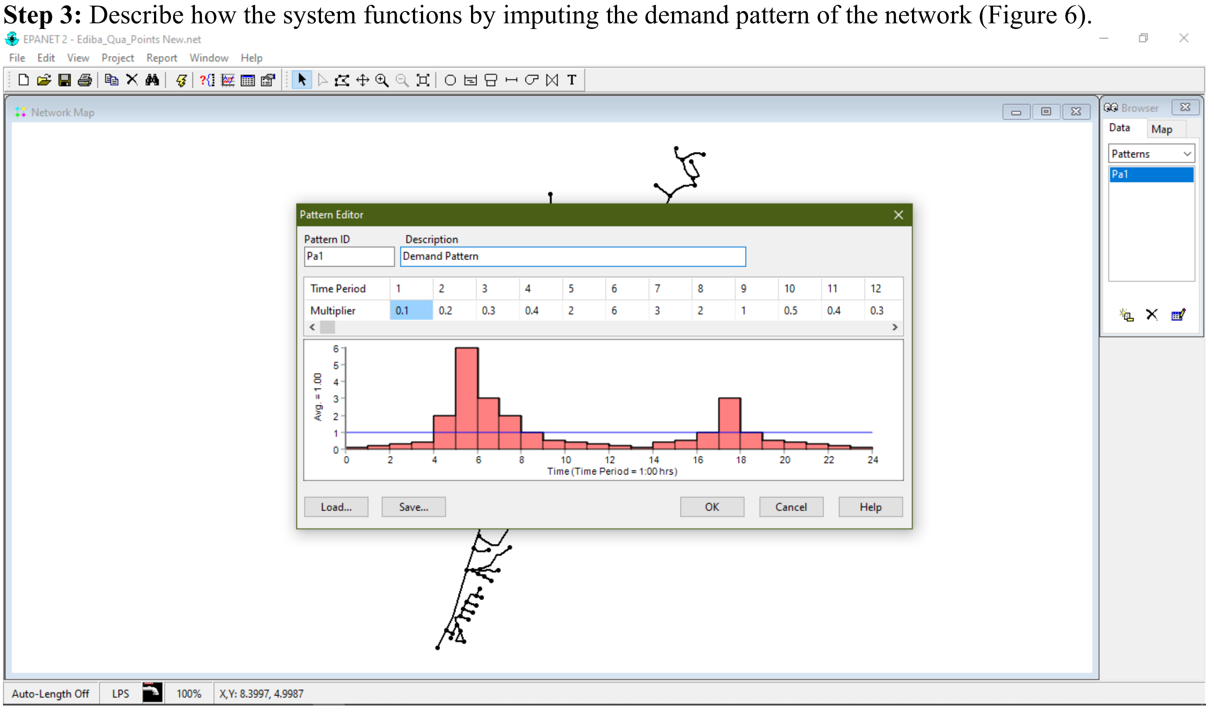

Figure 6. Multiplier

Step 4: Select and edit a set of analysis options (hydraulics, quality, times).
Step 5: Run a hydraulic/water quality analysis.
Step 6: View the results of the analysis which can be viewed in various forms i.e. tables, graphs, contour etc
Step 7: Repeat the procedure for three other distribution networks
Step 8: Export the file .inp format and import the .inp file in the software you wish to perform a comparative analysis

3.2 Procedures For Modelling A Water Distribution Network Using Watercad

Step 1: Export the file .inp format from Epanet and import the .inp file in WaterCAD (Figure 7)

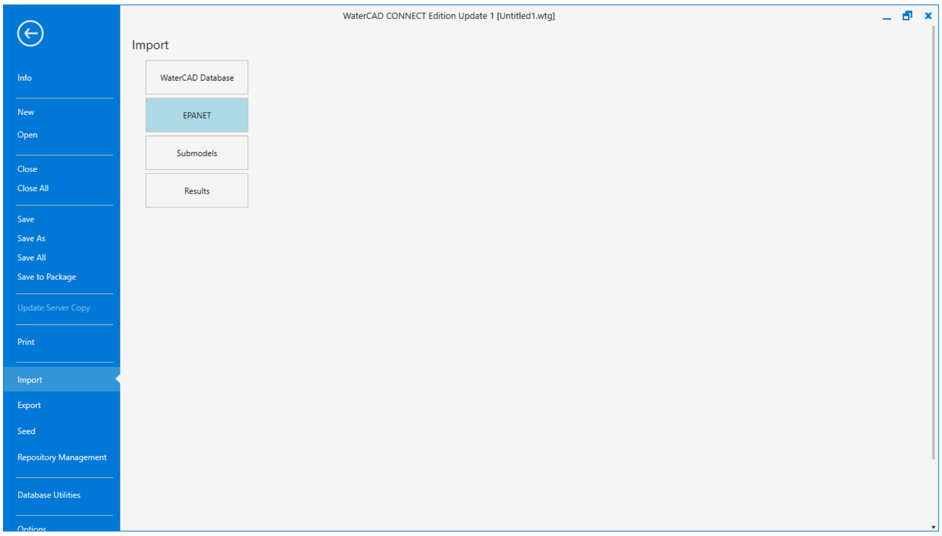

Figure 7. Importing INP Files to WaterCAD

Step 2: Compute the pipe network (Figure 8)

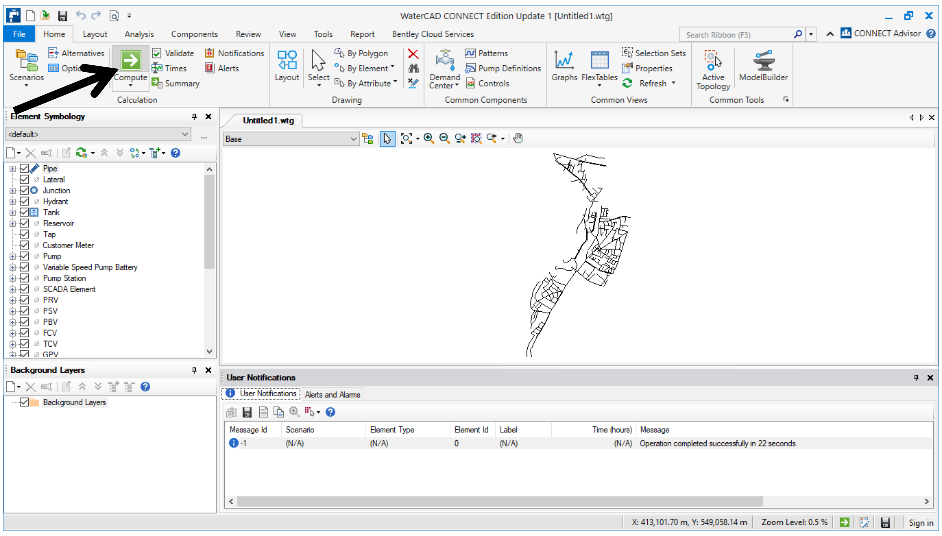

Figure 8. Running a Network Simulation on WaterCAD

Step 3: View the results of the analysis which can be viewed in various forms i.e. tables, graphs, contour etc
Step 4: Repeat the procedure for three other distribution networks

3.3 Procedure

A backdrop of each of the EWT map zones were loaded individually to EPANET and were used to model (skeletonization of water distribution) the existing pipe-borne water network of the metropolis in preparation for the pipe network data in a geometric network topology, placing the tank locations (points), pipes (lines) from the junctions (nodes).

The skeletonized water distribution of the first distribution zone (Diamond Hill) consists of 392 pipes with diameter ranging from 75-600mm, 329 nodes and 1 tank. The second distribution zone (Ediba Qua) consists of 283 pipes with diameter also ranging from 75-600mm, 257 nodes and 1 tank. The third distribution zone (Eta Agbor) which is the largest zone consists of 675 pipes with diameter also ranging from 75-600mm, 568 nodes and 1 tank (Figure 9). The fourth distribution zone (Ikot Effanga) consists of 324 pipes with diameter also ranging from 75-600mm, 290 nodes and 1 tank.

The arrangement of these elements (pipes, junctions, tanks etc) in the computer simulation package follows the link-node connectivity using the tool palette available in the computer model. The output of these models are meant to predict pressures in the system, velocities, head losses/energy dissipated, pipe flow rates, reservoir level, inflows, outflows and hydraulic grade (Figure 10).

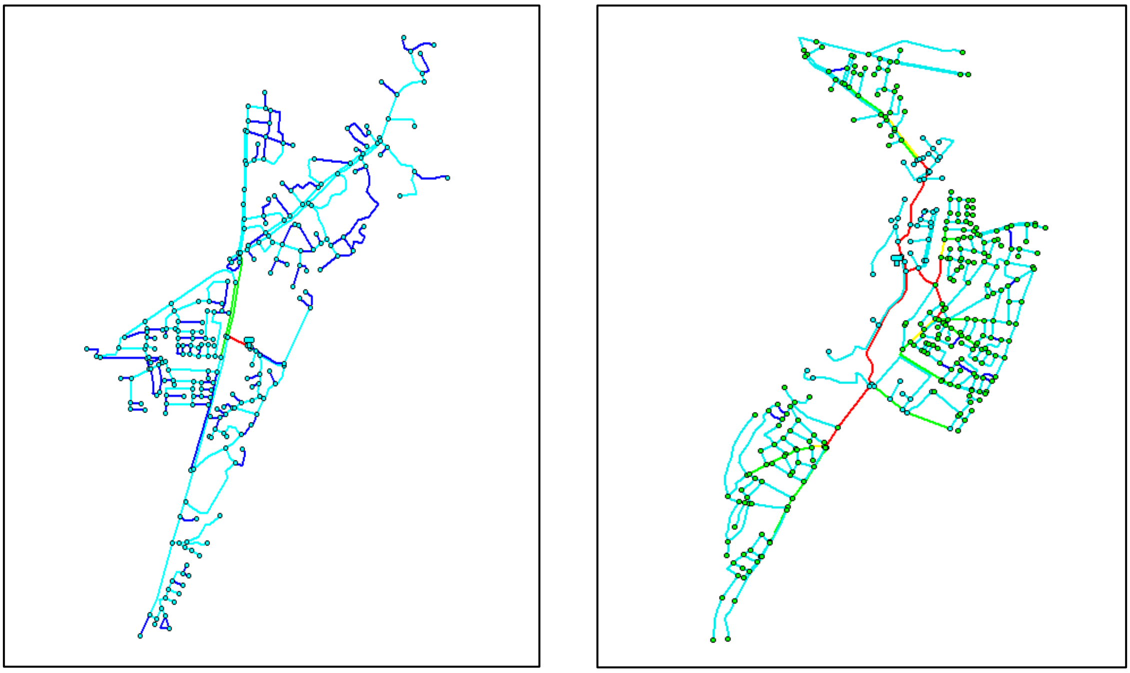

Figure 9. Diamond Hill And Ediba Qua Water Distribution network on Epanet

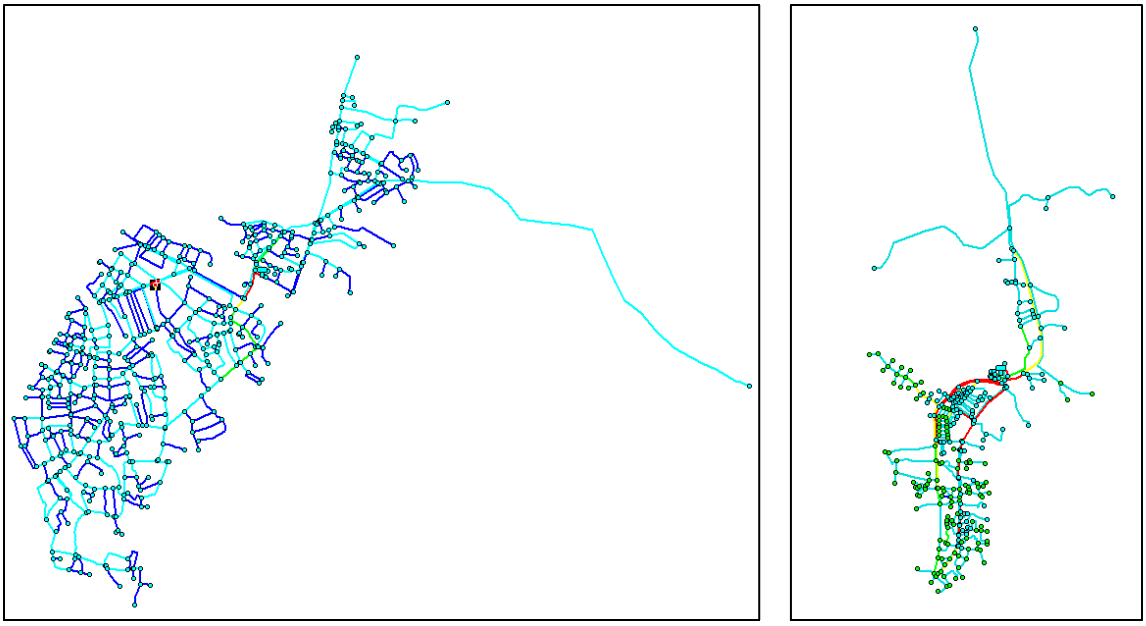

Figure 10. Eta-Agbor and Ikot Effanga Water Distribution network on Epanet

To simulate daily water use, the pressure at each node and the flow of water in each pipe were analyzed and tracked respectively with EPANET. Attributed data of the junctions, pipes and EWT's (Table 1) were imputed into the software programs. The ground elevation of these components which determines the pressure and flow rate of water to homes were imputed, especially as CRSWBL uses a gravity fed distribution system consistent with (Harding 2008).

The population demand was obtained after considering the population of the study area as 605,000, the average consumption for each distribution zones were recorded for a total of 50 sample points. The consumption per consumer(m3) and the number of occupants per household for each of the four distribution zones. were also considered to obtain the per capita consumption for each distribution zone. The demand at a particular junction was obtained by multiplying the per capita consumption by the number of buildings which

each junction serves and the average consumers per household which was then converted to LPS for consistency with simulations. The buildings were assigned to nodes using the Thiessens polygon method in which an estimated average of buildings around each node were used.
The simulation was run for each distribution zone, as each zone's EWTs serve the households in that zone.

Parameters set included the Hazen-Williams (H-W) head-loss formula to compute the hydraulic head loss by water flowing in a pipe due to friction with the pipe walls 2.
Epanet and WaterCad utilizes Hazen-Williams formula. The formula uses the following equation to compute head-loss between the start and end node of the pipe:
$hL = Aq^B$
Note:
  hL = headloss (Length),
  q = flow rate (Volume/Time)
  A = resistance coefficient
  B = flow exponent.
Where;

$$A = 4.727\ C^{1.852}\ d^{4.871}\ L$$
$$B = 1.852$$

Note:
  C = Hazen-Williams roughness coefficient (= 140)
  d = pipe diameter (ft)
  L = pipe length (ft)

Furthermore, a household water demand time pattern was assigned for each junction, representing demand at different times of the day.
The 24hour time period pattern was extracted from a field work done in CRSWBL which was evaluated by taking consumptions for 24hours across 20 points in Calabar. The average for each hourly frame were calculated and used, where water demand was modeled to be higher in the early hours of the morning and in the evening. This pattern also contributed in Extended Period Simulation (EPS) of pressure and flow rate at various times of day (6:00am, 12 noon, 6:00pm and 12am).

3.4 Calculating The Daily Consumption Pattern
After taking the average consumption at different points in the field, the consumptions per hourly timeframe are shown in the second column (Figure 11). The next steps are:

1. The total consumption for the day was calculated by adding up the consumptions for each hourly timeframe:

2. The average hourly consumption was calculated by dividing the total consumption by 24 hours.

3. The multiplier for each hour was then evaluated by dividing the consumption for the hour in question by the average hourly consumption

4. Check sum of multipliers to be equal to 24.

Table 1. Multiplier and Hourly Consumptions

Time Period	Hourly Consumption(l/h)	Multiplier
1:00	42.5	0.1
2:00	85	0.2
3:00	127.5	0.3
4:00	170	0.4
5:00	850	2
6:00	2550	6
7:00	1275	3
8:00	850	2
9:00	425	1
10:00	212.5	0.5
11:00	170	0.4
12:00	127.5	0.3
13:00	85	0.2
14:00	42.5	0.1
15:00	170	0.4
16:00	212.5	0.5
17:00	425	1
18:00	1275	3
19:00	425	1
20:00	212.5	0.5
21:00	170	0.4
22:00	127.5	0.3
23:00	85	0.2
24:00	42.5	0.1
TOTAL	10157.5	24
Average hourly consumption		**425**

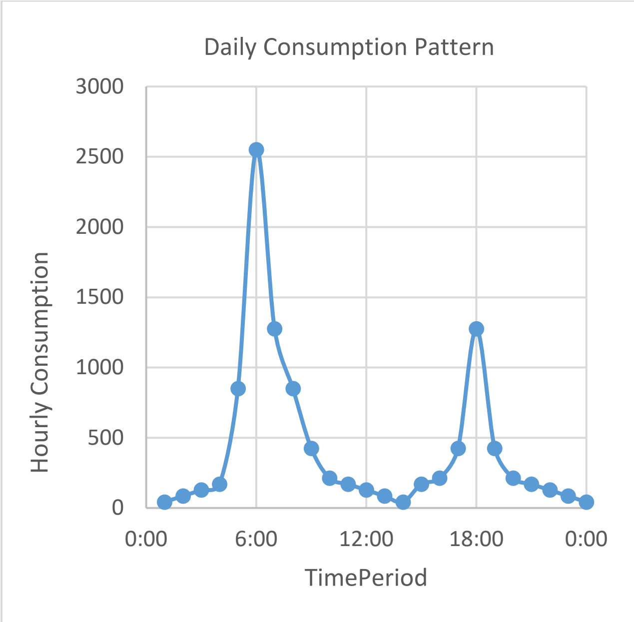

Figure 11. Daily Consumption Pattern

The minimal residual pressure for pipe network systems varies from one water agency to the next and between regions, according to (Alkali et al. 2017). A minimum pressure head of 25 meters and a maximum of 70 meters was proposed (Bhardvaj 2017). Due to a lack of local regulations, the American Water Works Association (1956) recommended a minimum of 15 meters and a maximum of 70 meters. Any pressure below 15m is considered inadequate and might indicate total water loss at the node. In a similar vein, if the pressure exceeds 70m, water hammer occurs where the water mains are vulnerable to damages (Bwire et al. 2015). For the purpose of this study a maximum value of 2 m/s and minimum of 0.1 m/s was adopted. A flow rate of at least 0.15 liter per second is also acceptable, according to the United Kingdom's Office of Water Services (Bharvaj 2017). A flow rate below the minimum would result in water flow problems at the consumer end of the pipes

4. Data Collection

Population data were sourced from the 2006 census data from the NPC and CRSWBL. The materials used for this study includes; 2015 map of pipe-borne water network and distribution zones, topographical map of calabar, number of occupants per household, consumer consumption then water distribution parameters such as; water demand, and also distribution network parameters such as; elevations, pipe diameter, pipe length, roughness coefficient finally EPANET software.

5. Results and Discussion

The results of the simulation are presented in colored maps showing the variations in pressure and flow rate at all the four water distribution zones in the study area. Using both models, the comparative results of the simulation were also discussed.

5.1 Results And Comparison Of The Two Models

The results of the simulation show the variations in pressure, velocity and flow rate at all the four water distribution zones in the study area. Using both models, the comparative results of the simulation were also discussed.
Using the ANOVA test, it was observed that there was no significant difference between the results from Epanet and Watercad.

5.1.1 Diamond Hill Distribution Zone Water Pressure And Flow Rate

For Diamond Hill zone, in the morning (6:00 am), water pressure was lower than 15m at 33 junctions (Figure 12). The other 295 junctions were within acceptable limits. At same time, flow was generally within workable measures, except for 15 pipes scattered around the zone. By 12:00 noon, in Diamond Hill zone, water pressure was generally within given standards as only 14 junctions had low pressures around same areas at dawn. The flow rate decreased considerably, with only the pipes with diameters higher than 200mm showing significant flow rates. The analysis revealed that at sunset (6:00 pm), pressure was low with 17 junctions exhibiting low pressures while 121 pipes had flow rates below 0.15LPS) (Figure 13). Water flow rate was substantially higher and sufficient enough for appropriate supply throughout the morning and evening hours, when water usage is at its highest. This, however, is still reliant on the pressure's quality. The low pressure in the area were due to leakages, rough pipes and buildings/residences on high elevation. Properties on higher elevations are the prevalent causes of the low pressures as the area is being served under gravity, pumps are needed to drive the water to underserved areas.

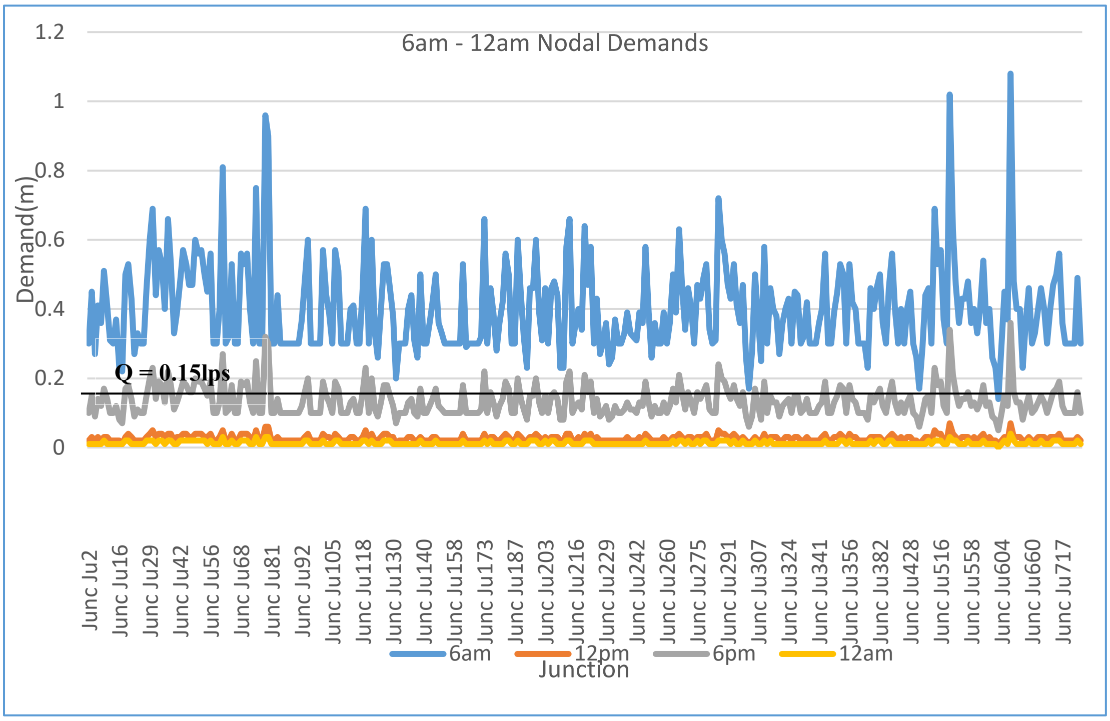

Figure 12. Diamond Hill Comparison Between Daily Demands

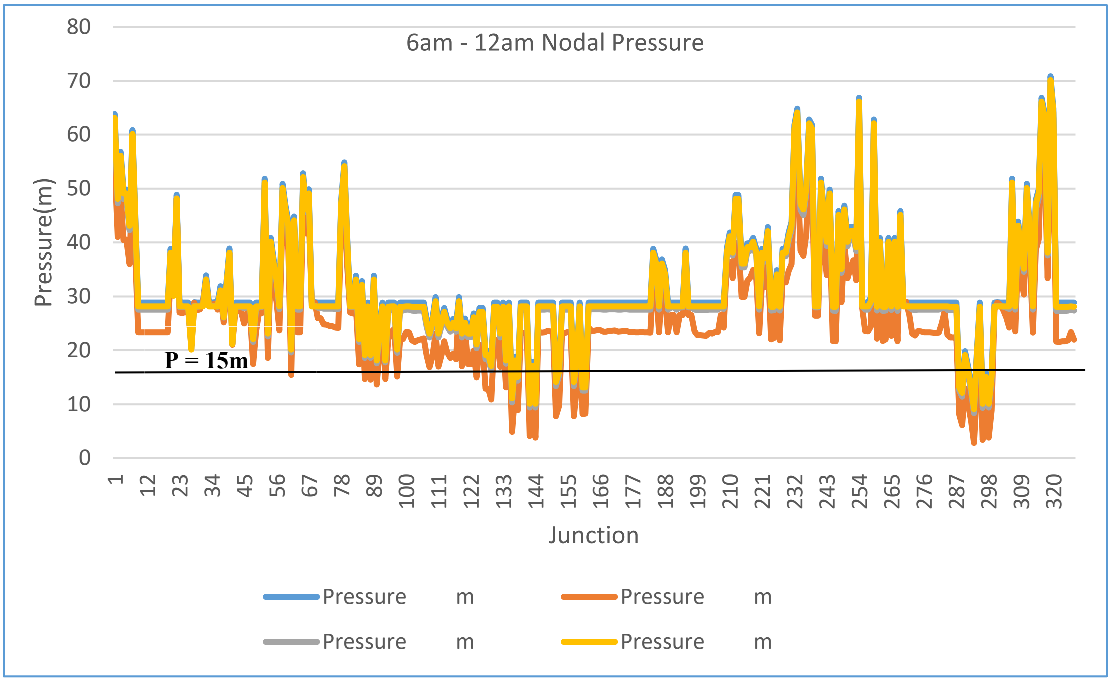

Figure 13. Diamond Hill Comparison Between Daily Pressure Head

5.1.2 Ikot Effanga Distribution Zone Water Pressure And Flow Rate

At dawn (6:00 am), pressure was less than required in 36.33 percent of the junctions representing 105 junctions in the area which means about 38 junctions had low pressures due to higher nodal elevations pipe roughness and sizes (Figure 14), Flow rate at dawn is shown to be below 0.15L in 10 pipes and high rates coming from the EWT main conduit. Pressure at 12:00 noon had similar characteristics with what was obtainable at dawn (Figure15). The difference is slight with 102 junctions having pressures less than the standard. At noon, the flow nearly fell to zero as expected. Here, only 75 pipes had sufficient flows while 247 were deficient of the required rate of 0.15L. By sunset (6:00 pm), pressure was depicted to have an increased rate, with 186 nodes above the permissible limit and 177 pipes had flows more than 0.15 LPS. The service would be most adequate in the morning and evening times were the demands will be higher, based on the water flow rate. The region of Ikot Effanga has the greatest elevation in the city. This might explain why there was low pressure at over 100 junctions throughout all simulated hours of the day. These areas, with their high altitudes and low pressure rates, are most prone to suffer intermittency in water supply, thus reducing their overall access to pipe-borne water.

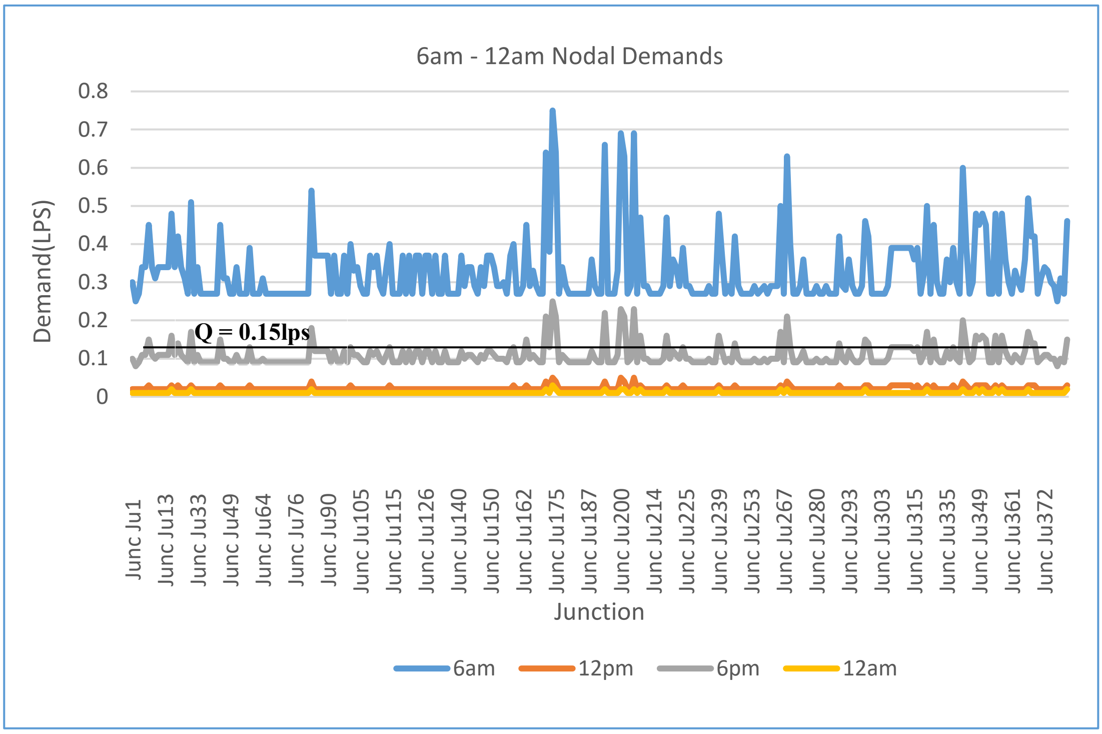

Figure 14. Ikot Effanga Comparison Between Daily Demand

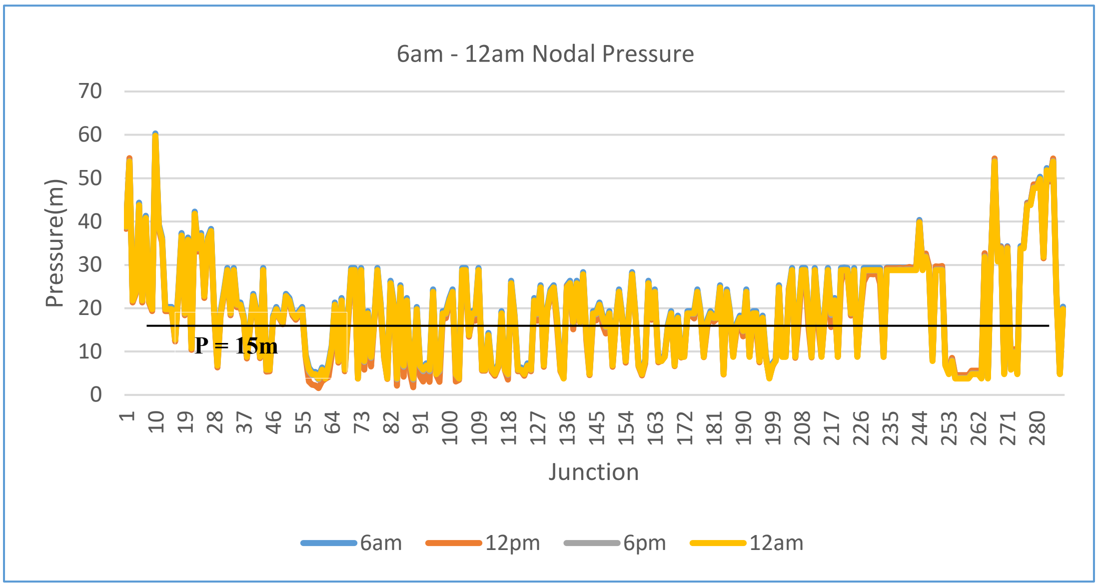

Figure 15. Ikot Effanga Comparison between Daily Pressure Head

5.1.3 Ediba Qua Distribution Zone Water Pressure And Flow Rate

At exactly 6:00 am, pressure fell below the 15m range at about 53 junctions (Figure16) No junctions exhibited pressures higher than the 70m standard. This is because most buildings are not as high as 70m in this zone but possess elevations higher than the threshold of the EWT. On the other hand, about 109 pipes had flow rates below 0.15 LPS. Noticeable, flow rate was highest in the pipes with larger diameters across the EWT northwards (Figure 17)... Pressure at 12 noon was very sufficient with just 27 junctions below the accepted range with no junctions having pressures higher than70m signaling very few areas having no cause for low and very high pressure concerns while flow rate decreased drastically at noon for most parts of the zone. The analysis also showed that, in the evening (6:00 pm), pressure significantly increased from what was deduced at day, although at this time, flow rate increased, even though as much as 180 of the 283 pipes had flows less than 0.15 LPS which would be as a result of collectively low demands at that period of the day. The implication of having pressures above the specification is that the water could destroy the facilities by causing frequent breakage of pipes and junctions. The Ediba Qua EWT was observed to be sited at a ground level, relatively higher than other areas within the zone, this informed the absence of low pressure within the zone but junctions with seemingly lower pressures were caused by pipe leakages and bursts from the mains.

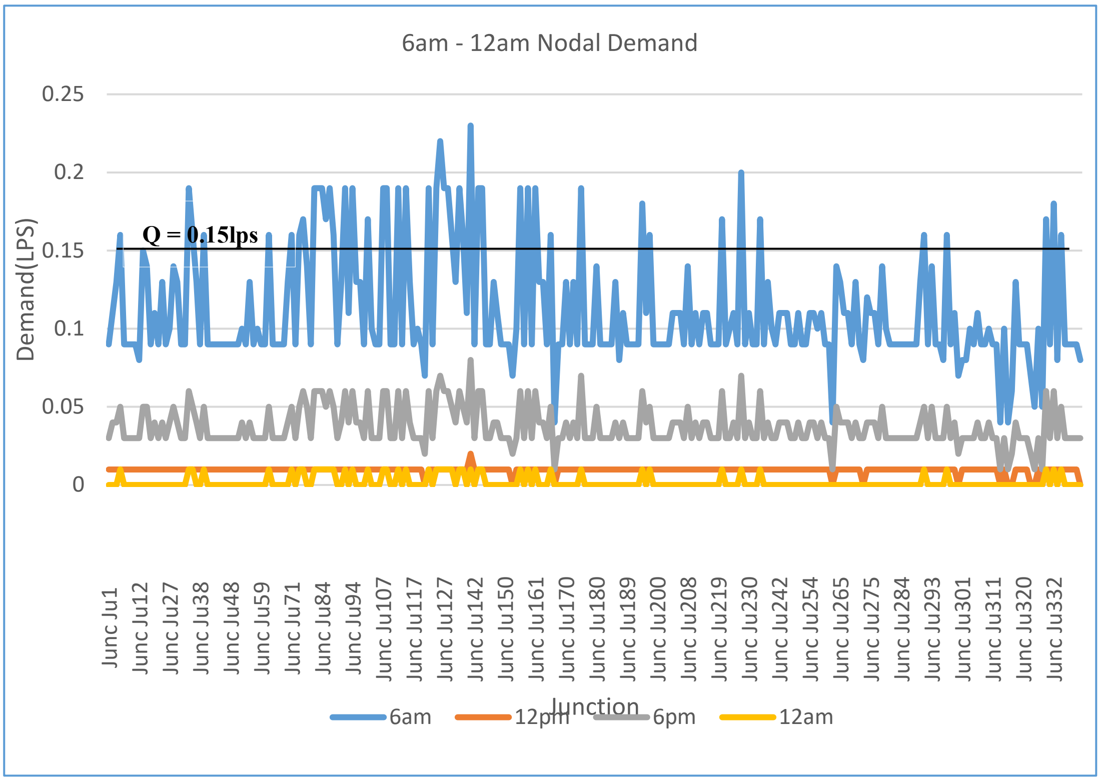

Figure 16. Ediba Qua Comparison Between Daily Demand

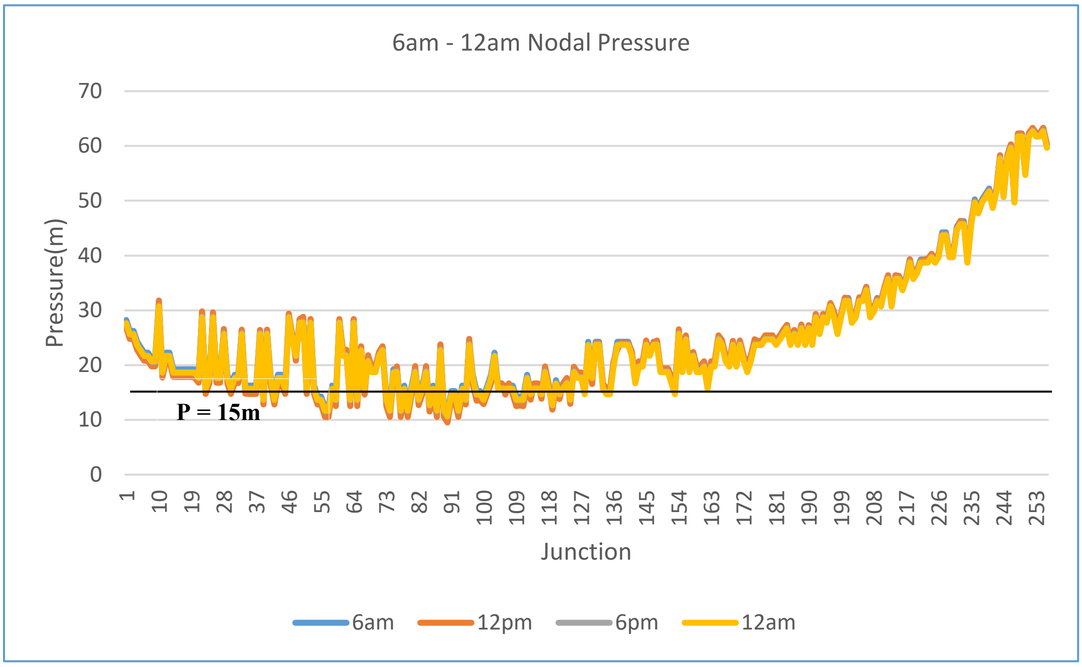

Figure 17. Ediba Qua Comparison Between Daily Pressure Head

5.1.4 Etta Agbor Distribution Zone Water Pressure And Flow Rate

During early hours of the morning (6:00 am) when water use is presumed to be high, the analysis showed that there were no low water pressure recorded. About 8 junctions exhibited pressures more than the70m bar (Figure 18). These high pressures tends to cause intense pipe bursts and water hammer causing appliances and pipe fixtures to fail. The flow rate analysis at this time also showed variation within the zone, generally below 0.15 LPS in 348 of the 568 pipes (Figure 19). By 12:00 noon, pressures for all junctions were above the 15m stipulated and flow rates were lower than 0.15 LPS with exemption to about 45 pipes. In the evening (6:00 pm), there was no significant difference with pressure values obtained by noon. No junction had pressures below the standard, 221 above 50m clustered around the EWT. 7 junctions depicted high pressures of concern. The implication of the low pressures portrayed in the morning period would most likely mean intermittency in water supply for residents of these locations while that of high pressures indicate the presence of a good amount of high rise buildings in that area thereby causing supplies of higher pressures.

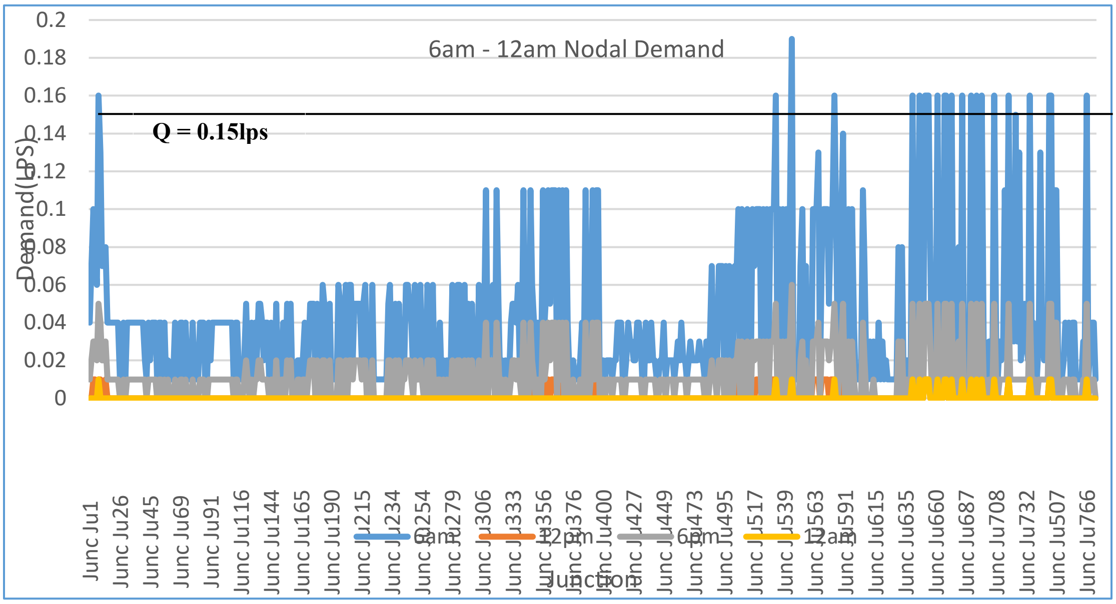

Figure 18. Etta Agbor Comparison between Daily Demands

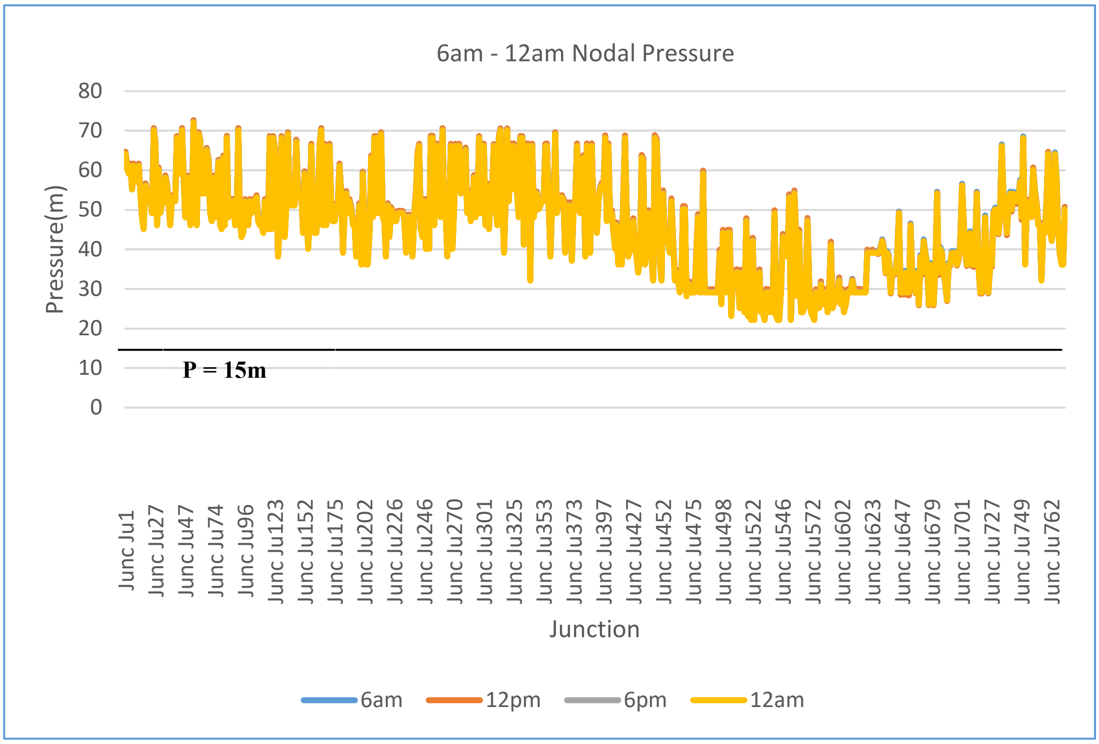

Figure 19. Etta Agbor Comparison between Daily Pressure Head

5.2 Proposed Improvements

Proposals were made as road maps for improving on general access to pipe-borne water in the region. There is need for CRSWBL to re-evaluate the pipe borne water distribution network of the city.
This is considering the new discovery of the behavior of the four distribution networks at various times in the city.

It is fundamental that concerned administrators are directed by the analytical results showing pipe-borne water pressure and flow rate inside the network. Likewise, since the pipe borne water distribution network is gravity fed, the low water pressure and flow rate issue can be controlled through establishment of electric pump stations in regions found to have low pressure.
These pumps would help to push water up to areas that experience water cuts and discontinuity because of low pressure and increment of the flow rate of the water when needed. Along these lines, pressure breaks should likewise be introduced on the observed high pressure lines. This is to check damage of pipe networks from outrageous pressure.

There is additionally need for explicit examinations on the conduct of water conveyance not just in Calabar city, yet in other Nigerian urban communities that have functional distribution systems

6. Conclusion

Recognizable from the analysis is the way that regions with low water pressure had high elevations, with cases around Ikot Effanga zone where some pipe intersections were laid on elevations higher than the height of the EWT. In a gravity fed distribution network, regions with such heights inside the network would probably encounter discontinuity and intermittency in water supply. Additionally, regions with the capability of pipe network infrastructural damage from water hammer instigated by high pressure were realized. The extended period simulation also mapped the flow activity of the water network inside the city. Perceptions from the outcomes likewise showed that there were altogether significantly more pipes with flow rates lower than 0.15 LPS at early afternoon in all the distribution zones, when water use is expected to be minimal or nearly insignificant.

A number of pipes in the system were inadequate resulting in very low velocities at several points in the system where nodal demands were substantially low as well. This is responsible for the enormous pipe water quality reduction and blockages in the distribution system thereby reducing the general system performance. It was seen that the water distribution system in Calabar city was significantly inefficient and requires rehabilitative concerns.

References

Agunwamba, J.C., Water Engineering Systems, 2nd Edition. Enugu: Immaculate publications Limited, pp. 181-190, 2000.

Webber, N.B., *Fluid Mechanics for Civil Engineers*. London: Chapman and Hall, 1971.

Rossman, L. A., *The EPANET2 Users Mannual, United States Environmental Protection Agency*.OH: Cincinnati, 2000.

UN.(2021, Jan. 16).*United Nations Sustainable Development Plan* [Online]. Available: http//www.un.org/sustainabledevelopment/water-aid-sanation-6604b7b1968a53ffg

Njoku, C., Okon, I., and Okpiliya, F., "Epanet for equitable water distribution, " *Epanet Spatial Modeling for Equitable Pipe-borne Water Distribution in Calabar Metropolis*, Cross river State, Southern Nigeria, vol. 54, pp. 2656-2675, Sep 2017.

CRSWBL, "Monthly Water Production and Distribution Report," *Volume of water distributed monthly in Calabar Metropolis*, Jan, 16, 2021.

CRSTU,"Cross River State Water Supply and Sanitation Policy Report," [Online],Aug 02 2021.Available : http://www.crswaterboard.com/documents/crs_final_draft_wss_policy.doc.

Abubakar, A., Sagar, N., "International Journal of Emerging Science and Engineering (IJESE),"*Design of NDA Water Distribution Network Using EPANET*, Vol 1, pp. 9, July 2013.

R, Bwire., N, Onchiri., Mburu, "International Journal of Civil Engineering and Technology" *Simulation of pressure variations withinKimilili water supply system using EPANET*. Vol 6, pp 28-38. Feb 2015.

Darshan,M., Namrata, K., Waikhom,S., "Computer Modeling of Water Distribution Network: ACase Study of Punagam Area, Surat City", In conf: National Conference on Water Resources and Flood Management, Surat, 2016.

Ayanshola,A.M., Sule, B. F., Assessment of flow pressure in selected zones of Ilorin township water supply network. *Journal of Research Information in Civil Engineering.*Vol 3(1), pp 83-101, 2006.

Alkali, A. N., Yadima, S. G., Usman, B., Ibrahim, U. A., and Lawan,A. G., Design Of A Water Supply ,2008.

Agunwamba, J. C., Ekwule, O. R., and Nnaji,C. C., Performance evaluation of a municipal water distributionsystem using WaterCAD and Epanet, *Journal of Water, Sanitation and Hygiene for Development.* pp 1-9, June 2018.

Anisha, G., Kumar, A., Kumar, J. A., and Raju, P. S., Analysis and design of water distribution network usingEpanet for Chirala Municipality in Parakasan District ofAndhra Pradesh., I*nternationalJournal of Engineering andApplied Sciences*Vol 3, pp 54–60.

Bhardwaj, V., Reservoirs, Towers, and Tanks: Drinking Water Storage Facilities, Tech Brief; National Drinking Water Clearinghouse, Tap Magazine, 2001.

Biographies

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