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HYDRAULIC ANALYSIS OF WATER DISTRIBUTION NETWORKS AT THE UNIVERSITY OF IBADAN

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ABSTRACT The importance of water to living things cannot be overemphasized. Some of the factors contributing to inefficient water distribution system in developing countries include low water pressure, intermittent service, and ageing infrastructure. The aim of this study is to determine the hydraulic adequacy of the university of Ibadan water distribution network using EPANET and GIS. The hydraulic analysis revealed that 103 out of 107 pipes have velocities below 1.5m/s, while 82 out of 83 junctions have pressures between 10 and 60 metres head which are within the prescribed standards. The booster stations at Amina way, Lander Road and Kurumi are at desirable elevations. It is recommended that hydraulic pumps should be introduced into the system in place of distribution by gravity to keep the velocities between the recommended values.

1. Introduction

Water is an important resource needed for the survival and sustenance of all living things. All sectors of economies are dependent on water; hence efforts are always continuously in place to ensure sustained water availability from adequacy of sources, distribution, and reticulation networks (Ajibade, 2005). The main sources of fresh water in Nigeria used for domestic and drinking purposes include surface waters sources (river, stream, pond, lake), groundwater and rainwater. Groundwater remains the major source for domestic purposes in Nigeria both in urban and rural area. Although surface waters are more economically viable in rural communities they are easily subjected to pollution (Sylvester *et al*., 2015). Nigeria is abundantly blessed with water resources; however, its availability varies with time, space and location; the north has low precipitation unlike the south which has high precipitation (NWSSP, 2000).

Water supply systems usually have combinations of some or all the followings: pumps, treatment plants, reservoirs, pipes and their fittings (Chin, 2006). In the process of delivering water for human use, water supply networks need enough pressure for water to reach every part of the network, for the establishment of adequate flow in the system. According to UNICEF (2000), some of the factors contributing to inefficient water distribution systems in developing countries include low water pressure, intermittent service and ageing infrastructure, thereby leading to a decline in water supply quality.

Insufficient pressure in water distribution systems cannot be divorced from unstable water supply (Kumar, 1998; Lee and Schwab, 2005). Water distribution can be achieved by gravity or by using pumps. Water stored in elevated tanks flows by gravity to distribution networks. This system subsists for small communities that do not have households with individual wells, since it could meet annual water demand and fire flow requirements (Hickey, 2008). Pumps are introduced to water supply and distribution systems to overcome gravitational force and to increase flow velocity and pressure. According to Navybmr (2018), two facilities which provide pressure in water supply systems are lift stations and booster pump stations. Lift stations designs includes pumps, level sensing probes, valves and pressure sensors and may also include a stand-by power generator in developing countries where power supply is unreliable. The booster station can be an open booster station or a closed booster station.

The need for effective water supply has led to the evolution of various modelling and analytical techniques, such as Geographic Information Systems (GIS) which can be used in the spatial and statistical analysis of water resources and systems to achieve effective management (Kalivas *et al.*, 2003; Udovyk, 2006). Spatial data is also referred to as geospatial data and it is the information about physical objects which can be represented by numerical values in a geographic coordinate system (Vairavamoorthy *et al.*, 2007). GIS facilitates the provision of an environment which displays model results from input and output data. It has proved to be an essential tool in analysing water distribution networks, thereby making it useful in this study. Hydraulic analysis which assesses the pressure and velocity of water in water distribution networks is therefore an important tool for determining the efficiency of water distribution systems. The synergy of GIS with other modelling tools enhances the overall management efficiency of water delivery systems (Bartolin *et al.*, 2008; Panagopoulos *et al.*, 2012).

EPANET is an excellent modelling tool which functions to perform extended simulation periods for hydraulic and water-quality behaviour within pressurized pipe networks (Rossman, 2000). It is a computer-based application which requires entry into the water network through a graphic interface by means of property dialogs (Bartolin *et al.*, 2008). Several research projects have been conducted on hydraulic analysis of different pipe networks. Ibitoye and Okende (2016) assessed water distribution network in Osogbo, Osun state, Nigeria. The study employed the use of GIS and remote sensing for optimizing the spatial distribution of the existing public water facilities and system. The study enabled the discovery that the existing water distribution network was not planned for an expanding Osogbo city. Suitable sites for new reservoirs were thus suggested for the city, for an effective water distribution. Other similar studies and research were as well carried out and these include Danilo (2009) which assessed potable water delivery in Dumaguet City and certain areas of Agusan del Sur Province in Philippines; Khadri and Chaitanya (2014) studied water network distribution in Chalisgaon City in India using remote sensing and GIS techniques; Yu *et al.* (2010) worked on the construction of a water supply pipe network based on GIS and EPANET model in Fangcun District of Guangzhou in China. Martinez *et al.* (2007) worked on the optimization of the operation of water distribution network in Valencia; Ramesh *et al.* (2012) carried out a simulation of hydraulic parameters in water distribution network using EPANET and GIS. Bartolin *et al.*, (2018) worked on the management of water distribution network using Arc View 3.2 and EPANET 2.0. Abdelbaki (2017) and Panagopoulos *et al.*, (2012) attested to the fact that the synergy of GIS with hydraulic modelling tools can greatly improve the design, operation, and management of water supply systems.

The University of Ibadan is in Ibadan at 7.4412° N, 3.9062° E. The university of Ibadan water works was designed to be supplied from Eleyele River and Awba Dam. The water distribution system consists of pipe networks of various sizes, with the total length of pipes being 82 kilometres. The university water treatment plant has capacity 6,000,000 litres/day. Some of the constraints impeding the adequate functioning of the water supply system to the university community are inadequate raw water in-take, ageing water distribution network and insufficient water treatment capacity. The present status of the water network calls for analysis in preparation for the overhauling of the system. Therefore, the aim of this study is to determine the hydraulic adequacy of the university of Ibadan water distribution networks. This was achieved by delineating a georeferenced digital map for the water distribution network, by analysing the hydraulic characteristics of the water distribution network and by determining suitable reservoir location based on the elevations within the university community.

2. Methodology

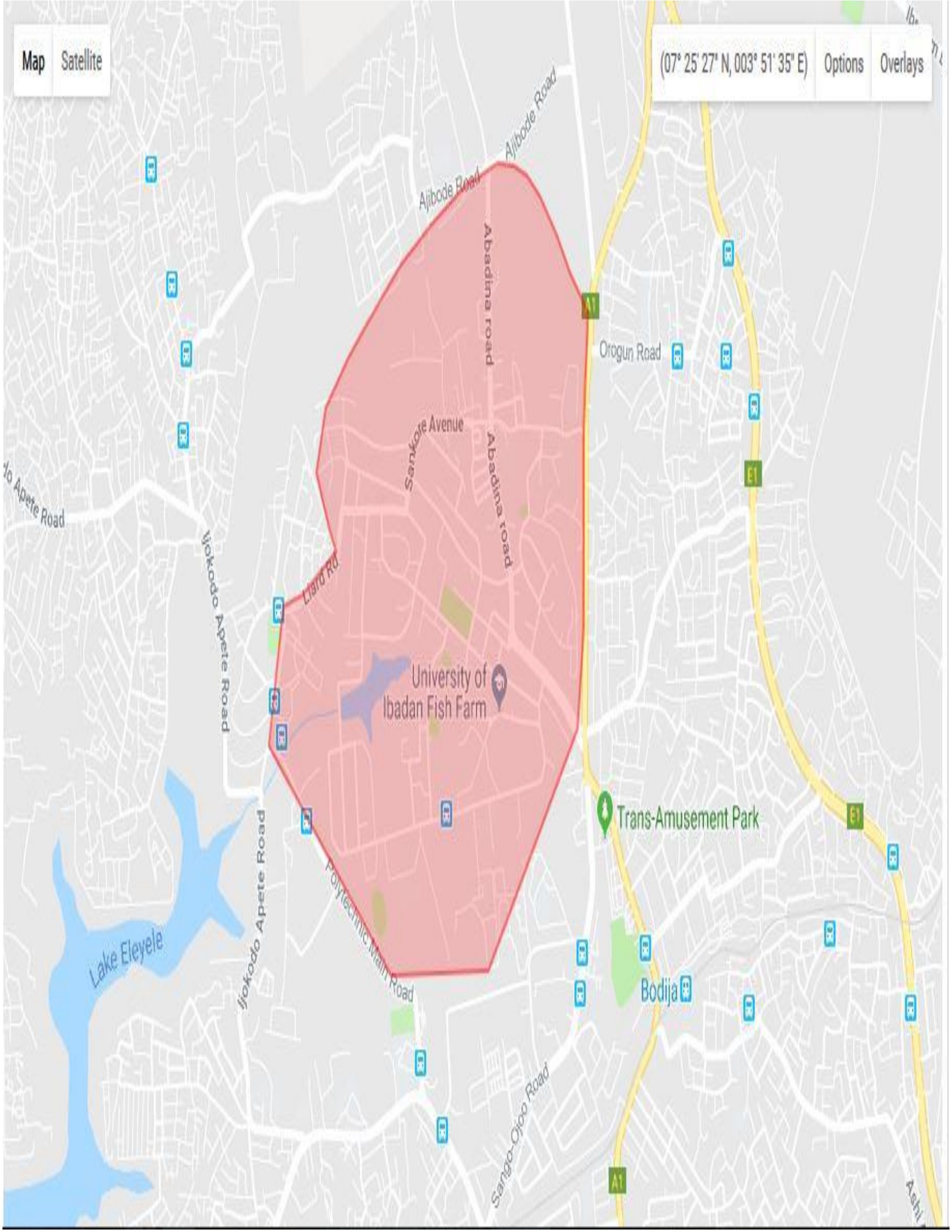
ArcMap was used to prepare the dataset features of the water distribution network serving the University. The provided analogue map was scanned into picture format and imported into ArcMap 10.2. The map was digitised so that layout of the pipes and nodes are reflected. Figure 1 shows the map of the University of Ibadan delineated from the map of Ibadan.

The pipelines and water nodes were created and imported to EPANET from GIS using SHP2EPA. Figure 2 shows the map of the existing pipe network for water distribution in the University of Ibadan. SHP2EPA detected the pipe lengths from the imported dataset while other properties such as elevations nodes, water demand at each junction, pump parameters, valve parameters, reservoir parameters and pipe diameters required, were modified on the EPANET windows.

Hazen Williams equation (equation 1) was employed for the calculation of head loss in the pipe. The frictional loss (H_f) in m is a function of the diameter of the pipe (D) in mm, length of the pipe (L) in m, flow rate (Q) in m^3/s and pipe roughness (C).

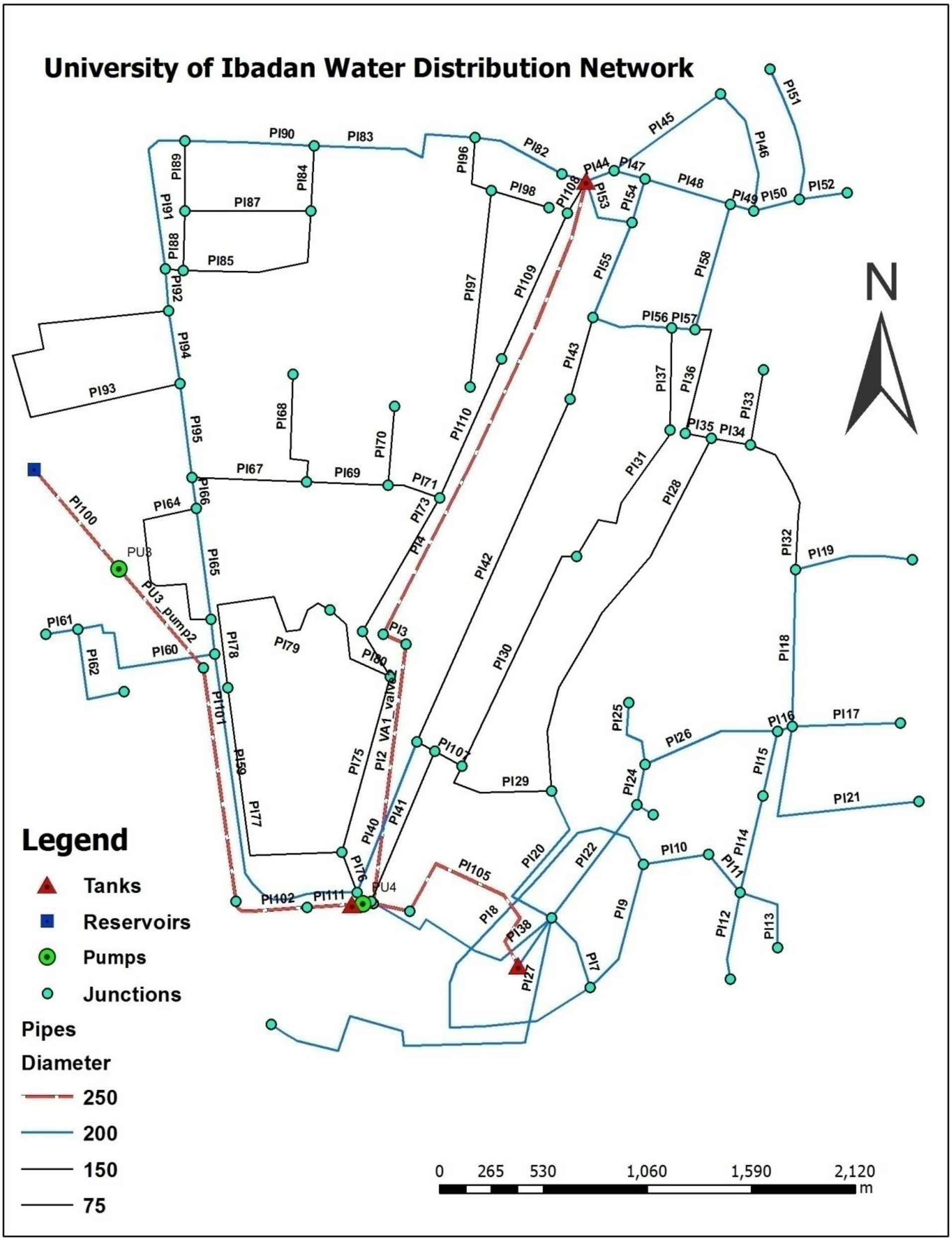
$$H_f = \frac{10.68L \times Q^{1.825}}{C^{1.852} \times D^{4.87}} \quad (1)$$

Figure 1 Mapped area of the University of Ibadan



Source: University of Ibadan

Figure 2 Existing water distribution network at the University of Ibadan



Source: University of Ibadan

Simple unit loading method was used for the estimation of the nodal demand based on the population. The number of consumers in specific areas around the nodes were determined and multiplied by the unit demand (per capita per day). The nodal demand which represents the peak hour demands often used for worst scenario simulations and designs was estimated with equation 2.

$$Nodal\ Demand\ (N_d) = \sum P_i \times D_j \qquad (2)$$

Where Pi = Population served by the node and Dj = Per capita demand.

EPANET recognises all tanks as cylindrical in shape, however, the major tanks at the booster stations at Amina way and Kurumi are non-cylindrical. The equivalent diameter (Di) for the non-cylindrical tanks were calculated with equation 3 according to Rossman (2000).

$$Di = 1.128\ \times \sqrt{cross}\ sectional\ area \qquad (3)$$

The analysis was simulated for 24 hours at 4 hours' interval to assess the node pressure and the velocities and flow rates of water in the pipe. The elevation of reservoirs on the campus are important factors in determining the efficiencies of the distribution network. The elevations of the land area covered by the University of Ibadan were determined from Digital Elevation Model (DEM) and extracted from ArcGIS 10.2. The points suitable for the location of reservoir were analysed and compared with the current locations.

3. Results and discussions

The existing water distribution network in the University of Ibadan community has main supply pipes with diameter 250mm and sub main and distribution pipes have diameters 200mm, and 150mm / 75mm, respectively (Figure 2). The details of the existing reservoirs are shown in Table 1.

Table 1 Parameters of water network distribution elements

Element	Lander	Amina Way	Kurumi
Service Reservoirs			
Capacity	1.2million	1.2million	490,280
Minimum Level (m)	1.22	1.22	1.22
Maximum Level (m)	3.66	3.66	3.66
Pumps			
Elevation (m)	210.53		
Maximum Head (m)	57		
Design Head (m)	80		
Shut Off Head (m)	83		
Design Discharge (m^3/hr)	125		
Maximum Discharge ((m^3/hr)	245		
Speed (RPM)	2955		

Table 2 Sections of simulated velocities in the pipes (m/s)

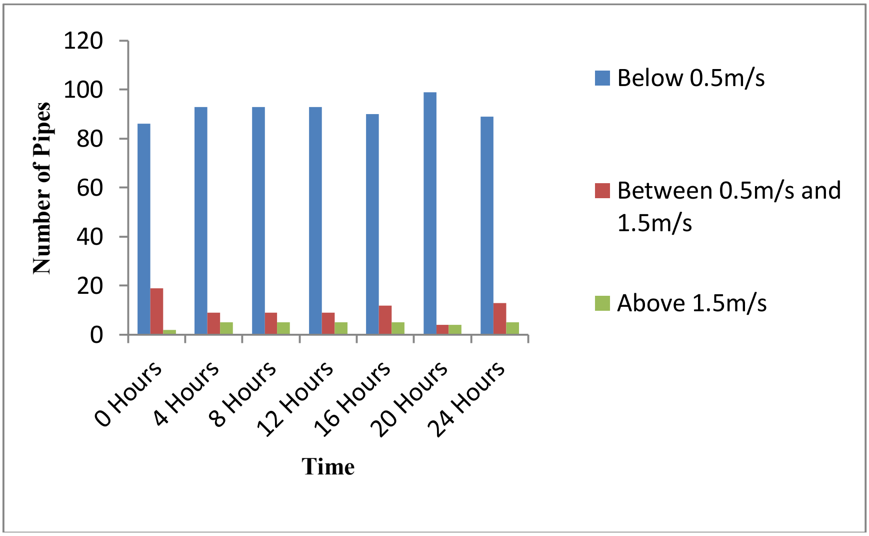
Pipes	0hrs	4hrs	8hrs	12hrs	16hrs	20hrs	24hrs
P16	29.95	1.99	1.81	1.87	1.74	0.68	1.93
P17	0.32	0.2	0.18	0.19	0.15	0.1	0.19
P18	1.04	0.07	0.06	0.06	0.05	0.03	0.06
P19	0.13	0.12	0.11	0.12	0.09	0.06	0.11
P20	4.06	0.64	0.59	0.6	0.59	0.18	0.63
P21	0.00	0.01	0.01	0.01	0	0.01	0.01
P22	0.42	0.22	0.2	0.21	0.18	0.10	0.21
P23	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P24	0.40	0.21	0.19	0.19	0.17	0.08	0.20
P25	0.00	0.01	0.01	0.01	0.00	0.01	0.01
P100	0.98	1.01	1.00	1.02	1.02	1.02	1.02
P101	4.56	4.53	4.53	4.51	4.52	4.51	4.51
P102	4.50	4.47	4.48	4.46	4.46	4.45	4.46
P104	0.02	0.00	0.00	0.02	0.02	0.01	0.00
P105	1.77	1.98	1.78	1.84	1.62	2.00	1.84
P111	4.56	4.53	4.53	4.51	4.52	4.51	4.51
P112	5.96	5.58	5.72	5.55	5.91	5.56	5.72

The main pipe conveys water from the treatment plant to the booster stations and tanks at Lander, Kurumi, and Amina way. The blue lines represent sub-main distribution pipes with 200mm diameter, while the black lines represent 150mm and 75mm diameter pipes. The pumps, tanks, and reservoir are also represented with different features on the EPANET window (Figure 2). The elevation of the University of Ibadan was found to lie between 170 and 260m above sea level by DEM. The areas at the water treatment plant, the international school and the booster stations remain the highest on the topography.

The simulated velocities of the water distribution network in the main distribution pipes P100, P101, P102, P111, P112, P104, P105, P12, P13, and P14 at 0:00 hour are respectively 0.98m/s, 4.56m/s, 4.5m/s, 4.56m/s, 5.96m/s, 0.02m/s, 1.77m/s, 0.9m/s, 0.24m/s, and 0.24m/s as shown on Table 2. Within 24 hours, the highest velocities in the main pipes were obtained for pipes P101, P102, P111, and P112 as 4.52m/s, 4.49m/s, 4.9m/s, and 5.70m/s respectively. All other main pipes have low velocities which lie between 0.11m/s and 2m/s. On querying the network on EPANET, it was found that 103 of the 107 pipes have velocities below 1.5m/s for the first 12 hours. Generally, a reduction in the flow velocities were observed during the non-peak demand periods. The pipes with water velocities below 0.5m/s are susceptible to being damaged because low flow velocities cause siltation, deposit build up and low shear in pipes (Abdelbaki *et al.*, 2017).

According to Bonnin (1986) and Dupont (1979), flow velocities between 0.5m/s and 1.5 m/s are best for water distribution. Flow velocities higher than 1.5m/s are capable of subjecting pipes to internal erosions and damages. Inadequate velocities in the distribution networks affects water quality and quantity. Figure 3 shows the plot of velocity distribution compared to the number of pipes in each velocity range.

Figure 3 Velocity distribution in pipes



The head loss in the PVC pipes used for the design analysis is generally small within the network as shown on Table 3. The highest head losses simulated were noticed in the main pipes P102, P102, P111 and P112 within the first 24 hours simulated. They are within the range 111 m/km and 185 m/km. The lowest head losses lay between the values 0 and 0.95 m/km. Majority of the head losses are below 0.5 m/km.

Table 4 shows the flow rates in the main and sub main pipes ranged from 60 l/s to 1052 l/s and 0.1 l/s to 99 l/s, respectively. The negative flow rates in some of the main and sub main pipes indicated the opposite direction of flow. That is, the pipe is supplying water to other pipes. The areas with high demands have higher flow rates. One of the 83 demand junctions (1.2%) have pressures below 10 metres head, while the remaining 82 junctions (97.6%) have pressures between 10 and 60 metres head, and one junction (1.2%) has a pressure above 60 metres head at inception, 16 hours of simulation and 24 hours of simulation. At 20 hours of simulation, none of the junctions has pressures below 10 metres head while one of the junctions has pressure above 60m and the remaining (82 junctions) have pressures between 10 and 60m. These show adequacy of the water distribution system; since the node pressure head of an effective system must not be below 7m or above 70m (Bonnin, 1986; Dupont, 1979). Table 5 shows the elevation of the junctions above sea level and Figure 4 compares the node pressures simulated for the water distribution network.

Table 3 Sections of the simulated head losses in the pipes (m/km)

Pipes	0hrs	4hrs	8hrs	12hrs	16hrs	20hrs	24hrs
P16	1.08	1.09	0.93	0.97	0.88	0.11	1.04
P17	0	0	0	0	0	0	0
P18	1.04	0.98	0.85	0.87	0.84	0.07	0.95
P19	0	0	0	0	0	0	0
P20	4.06	3.89	3.34	3.45	3.3	0.35	3.77
P21	0	0	0	0	0	0	0
P22	0.42	0.54	0.43	0.48	0.35	0.11	0.48
P23	0	0	0	0	0	0	0
P24	0.40	0.48	0.39	0.42	0.33	0.09	0.43
P25	0	0	0	0	0	0	0
P100	6.59	6.91	6.85	7.06	7.02	7.08	7.05
P101	112	111	111	110	110	110	111
P102	110	108	109	108	108	108	108.
P104	0	0	0	0	0	0	0
P105	19.6	24	19.8	20.93	16.63	24.50	21.03
P111	112	111	111	111	110	111	111
P112	185	164	172	162	182	162	171

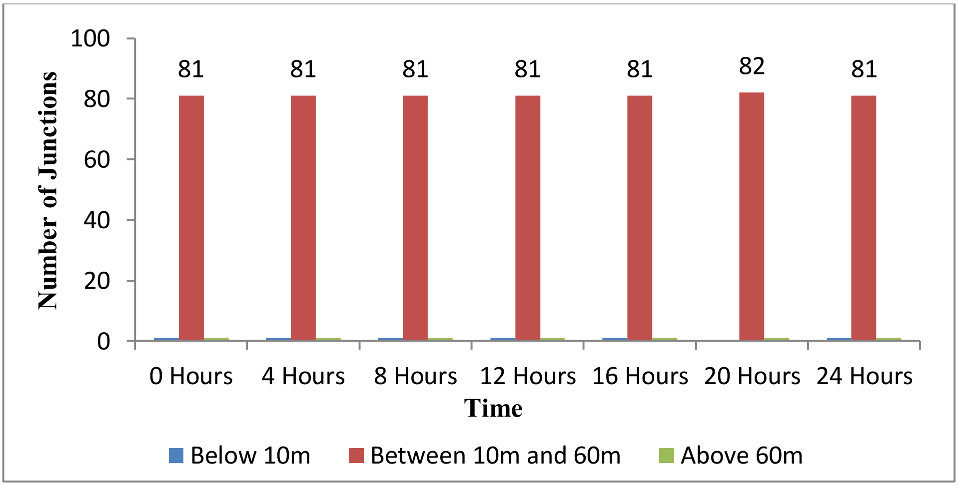
Table 4 Sections of simulated water flow rates in pipe distribution networks (l/s)

Node	0hrs	4hrs	8hrs	12hrs	16hrs	20hrs	24hrs
P16	36.4	36.6	33.5	34.4	32.6	10.7	35.6
P17	0.20	0.52	0.40	0.48	0.20	0.52	0.40
P18	35.6	34.6	31.9	32.4	31.8	8.58	34.1
P19	0.30	0.78	0.60	0.72	0.3	0.78	0.60
P20	74.4	72.7	67.0	68.2	66.5	19.6	71.4
P21	0.30	0.78	0.60	0.72	0.30	0.78	0.60
P22	22.0	25.1	22.2	23.4	19.9	10.8	23.4
P23	0.10	0.26	0.20	0.24	0.10	0.26	0.20
P24	21.4	23.5	21.0	22.0	19.3	9.25	22.2
P25	0.30	0.52	0.40	0.48	0.20	0.52	0.40
P100	-173	-178	-178	-180	-180	-181	-180
P101	805	800	801	797	798	797	797
P102	796	790	791	787	788	787	787
P104	-3.0	-0.03	-0.2	-3.39	-3.49	-2.08	-0.02
P105	-312	-349	-314	-324	-286	-353	-325
P111	806	800	801	797	798	797	797
P112	-1052	-986	-1011	-980	-1044	-982	-1011

Table 5 Sections of the node elevation and simulated node pressure head (m)

Node	El. (m)	0hrs	4hrs	8hrs	12hrs	16hrs	20hrs	24hrs
J1	198	31.92	31.5	32.2	31.89	33.41	31.90	32.78
J2	200	29.87	29.87	30.39	30.15	31.40	30.20	30.91
J3	216	14.64	13.64	14.22	13.95	15.80	14.00	14.87
J4	208	30.44	31.32	30.23	30.42	30.47	32.80	31.34
J5	222	16.37	17.22	16.15	16.33	16.41	18.80	17.25
J6	220	18.32	19.15	18.09	18.26	18.37	20.70	19.19
J7	220	18.28	19.1	18.05	18.22	18.33	20.70	19.15
J8	210	28.24	29.06	28.02	28.18	28.31	30.70	29.11
J9	210	28.24	29.06	28.02	28.18	28.31	30.70	29.11
J10	204	34.24	35.06	34.02	34.18	34.3	36.70	35.11
J11	210	28.14	28.95	27.93	28.08	28.22	30.70	29.01
J12	216	22.08	22.89	21.88	22.04	22.17	24.70	22.95
J13	210	28.03	28.84	27.83	27.99	28.13	20.70	28.90
J14	210	28.03	28.84	27.83	27.99	28.13	20.70	28.90
J15	208	29.51	30.35	29.41	29.55	29.71	32.70	30.42
J16	190	47.51	48.35	47.41	47.55	47.71	50.70	48.42
J17	207	31.03	31.84	30.83	30.99	31.13	33.70	31.90
J18	216	20.86	21.81	20.93	21.07	21.18	24.70	21.87
J19	222	16.26	17.19	16.04	16.21	18.32	20.70	19.13
J20	220	18.26	19.09	18.04	18.21	18.32	20.70	19.13

Figure 4 Simulated node pressure of water distribution network



4. Conclusion

It is evident from the study that the water supply network facilities of the university is well distributed and adequate, provided sufficient water is supplied from the source. The locations of the reservoirs at the four booster stations within the community are recommended to be retained since these are the highest topography within the university. Some of these reservoirs at the booster stations can be supplied simultaneously from the source. For examples, according to the water engineers on site, the reservoirs at Amina and Kurumi are simultaneously supplied water during the pumping period (18 hours). Flow Control Valves (FCV) are also available to direct water to the needed reservoir according to prevailing conditions.

It is however recommended that pumps with adequate capacities be introduced to the points with low velocities in the supply system instead of sole distribution by gravity; this is so that sufficient flow velocities and flow rates can be enhanced in the pipes. The node pressure in the system is however found to be adequate for effective and efficient water delivery.

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