



HYDRAULIC PERFORMANCE AND OPTIMAL SITING OF SERVICE RESERVOIRS IN THE ILORIN WATER DISTRIBUTION SYSTEM

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Abstract: *This paper presents the evaluation of the hydraulic performance of Ilorin metropolitan water distribution system with the aim to determine the optimal locations of service reservoirs and nodal pressures for improve water supply. In an attempt to improve the water services in Ilorin, the Kwara State Government proposed the construction of additional service reservoirs at different locations within the metropolis. The GIS was used to provide georeferenced locations of pipes, nodes, reservoirs, while the Hydraulic conditions were performed with EPANET 2.2 software in order to determine the output pressure at demand nodes for various scenarios under consideration. Ten cases were considered using the location of the service reservoirs and the quantity of water distribution to the study area. The pressure distribution at the nodes were determined for the ten cases. The minimum and the maximum nodal pressures obtained were 10 m and 84 m respectively based on case IV. These are favorably comparable with the recommended values for satisfactory performance. Case IV has the highest percentage number of nodes pressure that fall between 25 m and 84 m. About 20% of the nodes have pressure below 25 m and none above 84 m. This will rule out the possibility of pipe bursting as a result of excessive pressure in the pipeline. Hence Case IV has the optimal nodal pressure distribution and can be concluded that the study provide a suitable model for appropriate location of the service reservoirs based on pressure requirement at demand nodes.*

Key words: Service reservoirs, Pipe networks, Nodal Pressure, water supply, EPANET

1 Introduction

The Ilorin water Distribution System is a critical urban infrastructure designed to convey treated water from production sources to residential, commercial, and institutional users. However, rapid urbanization, population growth, unplanned spatial expansion, and aging infrastructure have imposed significant stress on

the existing network, resulting in persistent challenges related to hydraulic performance and service reliability. These challenges are manifested in inadequate and highly variable pressure levels, intermittent water supply, excessive head losses, frequent pipe bursts, suboptimal siting of existing service reservoirs and inequitable water distribution across different zones of the metropolis. One of the main objectives of water supply system is to provide potable water for domestic use, industrial use and

fire protection. Economics and social development, environment and public health hinge on water and the extent of its availability (Haddadin, 2001).

An essential part of all water supply system is the distribution system, the water has to get to the consumer through the network of pipelines with a minimum specified residual pressure at sufficient quantity without degrading its quality from the sources or treatment plant (Chenevey, 2022). Among other components, includes hydraulic elements such as pumping stations, storage reservoirs, transmission and distribution supply main, valves and fire hydrants, transport water from a treatment facility to the end users (Widiarti et al., 2020; Ganjidoost et al., 2021). The service reservoirs are strategically located for maximum benefits, normally they are positioned near the centre of use, but in large metropolitan areas, a number of them may be located at key points in the distribution network system. A central location decreases friction losses by reducing the distance from supply point to the area served. Positioning the reservoir so that pressures may be approximately equalized is an additional consideration of importance (Okeola, 2000; Okeola, 2021).

A service reservoir can be considered to have failed if it runs dry, or failed to produce desired pressure at demand nodes. It is also possible to describe the reliability or lack thereof of a reservoir through its failure behavior (Zyl et al., 2008a; Zyl et al., 2008b). Service reservoirs were built at various locations within the metropolis in order to boost the pressure at different locations. The idea behind the construction of these reservoirs was to store the excess water during the low demand periods and release at peak periods. This approach aimed at meeting the demand of water network pressure at various nodes.

Various techniques exist for the optimizing of a water distribution system example includes: linear programming, non-linear programming, fuzzy logic, stochastic dynamic programming, simulated annealing, Geographic Information System (GIS). The use of GIS is increasingly being co-opted to assign water demand to network nodes based on user classifications such as residential commercial, industrial, institutional, etc (Raju et al., 2000; Fillion et al., 2007). Water professionals and researchers had found the Environmental Protection

Agency Network Evaluation Tool (EPANET) software useful in the design, operations and improvement to various water network distribution systems because of its simulation capabilities (Ashraf et al., 2025; Amato, 2014; Adeniran and Oyelowo, 2013; Hossain et al., 2021). Amoo et al., (2025) explores modern spatial databases for meaningful technical progress using the QGIS server to host a web-based geocoding platform to view the production, transmission, and delivery of drinking water from source to household users according to the capacities planned by water supply system. The resultant results gives information on pipe network, road connection, catchment boundary, slope, and sub-catchment geometric properties demonstrate the utility of a web-based online Map plugin in the GIS environment as a data management, scenario analysis, and decision support tool in managing water infrastructure for an expanding metropolitan city like Ilorin, Kwara State.

Despite the existence of service reservoirs across different supply zones in Ilorin, many consumers still experience inadequate service levels, ranging from intermittent supply to critically low pressures. Typically, distribution systems are designed to satisfy predefined levels of service often expressed as a minimum acceptable level of pressure at the critical nodes, i.e., the point with the lowest pressure under peak demand conditions (Mckenzie and Wegelin, 2009; Tian et al., 2023). In addition, there may be certain fire-flow requirements which can over-ride the normal consumer requirements (Bhave and Gupta, 2006). Ensuring compliance with a minimum pressure threshold is essential for consumer satisfaction and system reliability (Jacobs and Strijdom, 2009).

Accordingly, this study evaluates the existing Ilorin water distribution system using hydraulic simulations, identify the optimal combination of service reservoir capable of delivering satisfactory nodal pressures across the network. The methodological approach presented herein can also be applied to assess the most efficient strategies for managing nodal pressures in existing system or guiding the design and development of a new distribution networks in the metropolis (Mawengkang et al., (2023).

2. Methods and Materials

2.1 Study Area

Ilorin, the capital city of Kwara State, Nigeria is located between latitudes 8° 25'N and 8° 32'N longitudes 4° 30'E and 4°41'E (Figure 1). It presently occupies an area of about 89 Km² (Adeleke, 2010; Atomode, 2013). The population of the city was estimated to be 777,667 in

2007 and projected to 1,358,910 in 2024 for the analysis. A population density of 9 persons per 1000 m² (9,000 persons/km²) was adopted for the study area. This is in line with the Nigerian Institute of Town Planning, NITP (2014) indicates that medium-to-high density urban residential areas typically accommodate 8 – 10 persons per 1000 m².

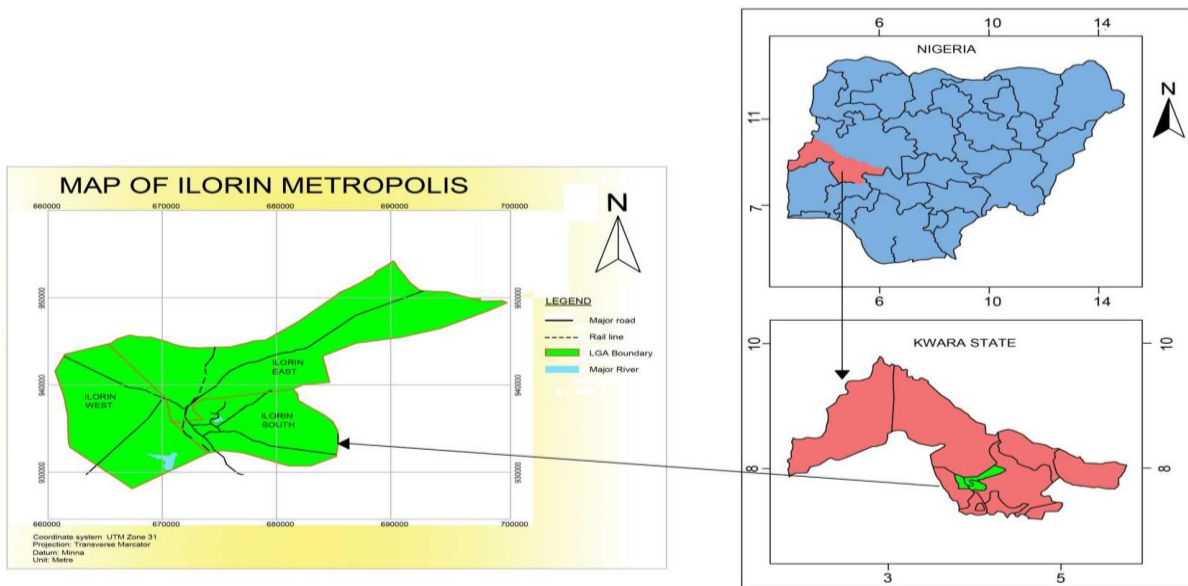


Figure 1 Map showing the study area in Kwara State

Table 1: Summary of the Main Features of the Water Works serving Ilorin

Storage Dam	Dam Reservoir Capacity x 10 ⁶ m ³	Treatment Plant Production Capacity (x 10 ³ m ³ /day)
Asa	43.00	55.000
Agba	3.10	18.184
Sobi	3.00	9.092
Total	49.10	82.28

2.2 Basic Features and Data

2.2.1 Water production

Water supply system of Ilorin is based on surface water drawn from Agba, Asa and Moro Rivers. These three

rivers have dams constructed across them. They also have treatment plants to supply water to the metropolis and its environment. The dams have total reservoir capacity of about 49 x106 m3 with total treatment plant full capacity production of 82,276 m3/day. Table 1 shows the summary of the main features of the water works.

Table 2: Location and Capacities of Service Reservoirs in Ilorin Township

S/No	Reservoir type	Location	Source of treated water	Capacity (m ³)	Remarks
1	Underground Concrete	GRA / Fate quarters	Agba	4,600	In use
2	Eastern Ground level	Tanke	Asa	10,000	In use
3	Western Ground level	Adewole Estate	Asa	10,000	In use
4	Overhead Concrete	Unilor Teaching Hospital	Asa	4,600	In use
5	Overhead steel	Olanrewaju Estate, Offa garage	Agba	227.30	In use
6	Overhead steel	Oke Sobi, Sobi road	Sobi	227.30	In use
7	Overhead steel	Central Mosque	Asa	227.30	In use
8	Overhead steel	Central Mosque	Asa	454,609	In use
9	Overhead steel	Sobi Road	Sobi	454,609	In use
10	Overhead steel	Unity Taiwo junction	Agba	454,609	In use
11	Overhead steel	Olanrewaju Estate	Agba	454,609	New
12	Overhead steel	Kwara hotel	Agba	454,609	New
13	Overhead steel	GRA / Fate	Agba	454,609	New

2.2.2 Service reservoirs

However, government proposed more service reservoirs and for effective utilization there is need to optimize the location and the number needed for an effective distribution system. Before 1999, seven service reservoirs were connected to the network (Sule, et al., 1999). Another three overhead steel tanks service reservoirs were introduced in 2001 to enhance the distribution system making 10 existing service reservoirs. However three more service reservoirs were proposed as an additional to further boost the performance of water distribution network in Ilorin. The locations, capacities and the status of the 13 service reservoirs in Ilorin Township are as presented in Table 2. Water pumped from Asa, Agba and Sobi clear water tanks are normally stored in service reservoirs from where they are delivered by gravity to the various demand areas.

2.2.3 Pipe network system

The distribution system in the metropolis is primarily dictated by street patterns, topography, water demand and

location of treatment and service reservoirs. This work took account of main trunk lines, which transport water between separate sections of some important areas. It also included some transmission lines, which link some important routes. Figure 2 shows pipe layout and location of tanks for the study area, while Figure 3 depicts the extended Pipe layout and location of service reservoir for the study area.

Figure 4 is the skelitized pipeline layout for the metropolis showing the pipeline dimensions for the study area. The area considered has a total number of 19 pipes, 15 nodes and 5 loops as shown in Figure 4

2.2.4 Estimation of flow based on consumption

The scaled pipe network map obtained from the Kwara State Water Corporation (KSWC) was digitized and the area of each loop of the network considered were determined. In order to determine consumption for each loop, average demand required and an average consumption of 120 l/c/d was used (Okeola, 2000). Table 3 presented the area, population, pipe and total length for each loop, average demand and consumption for each loop.

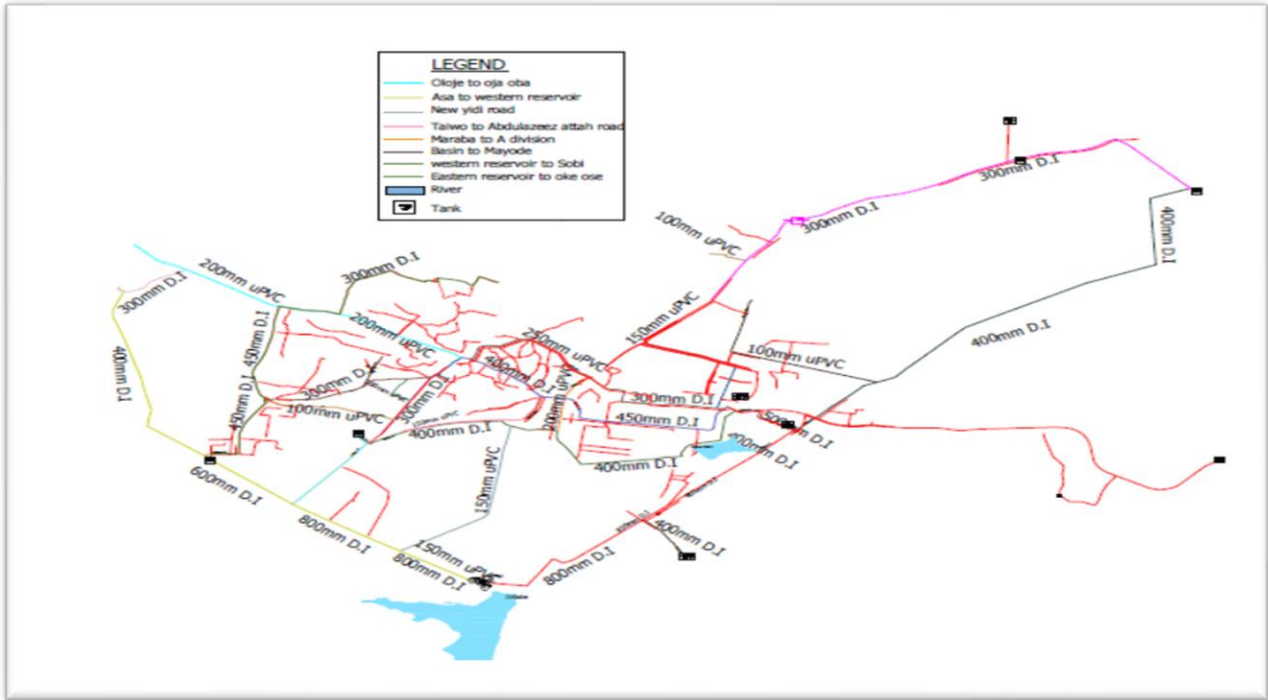


Figure 2 Pipe layout and location of service reservoirs for the study area

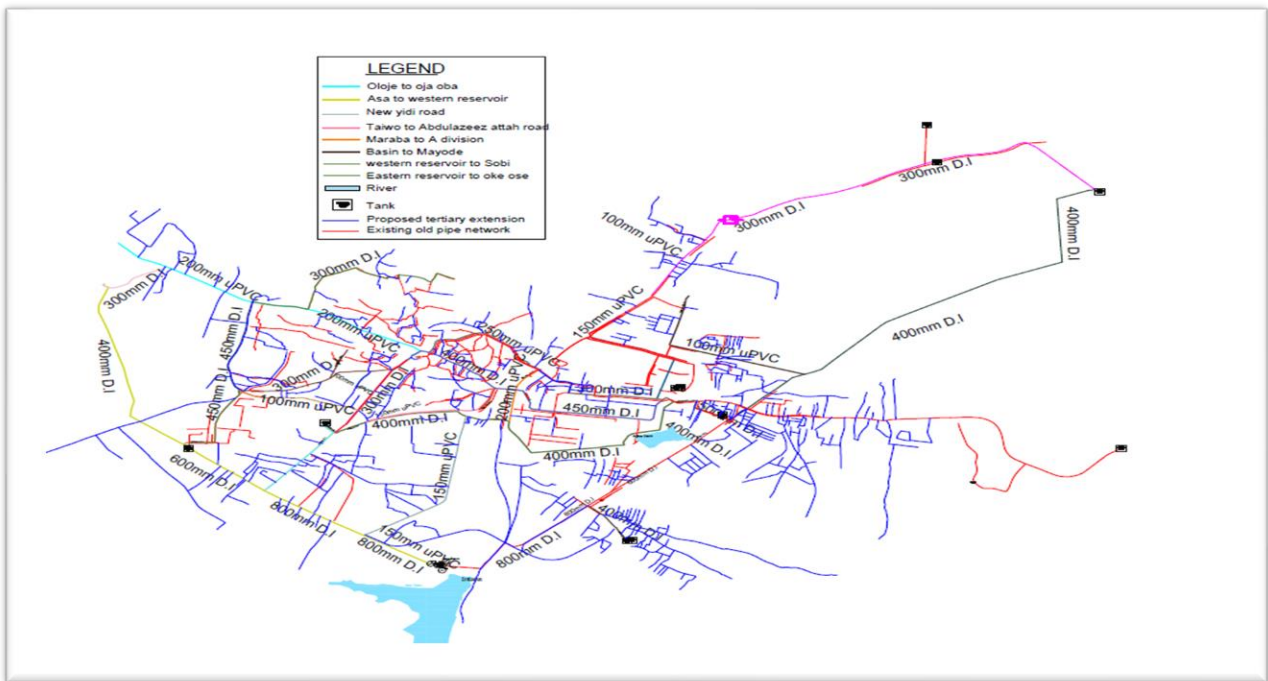


Fig. 3 Extended Pipe layout and location of service reservoir for the study area

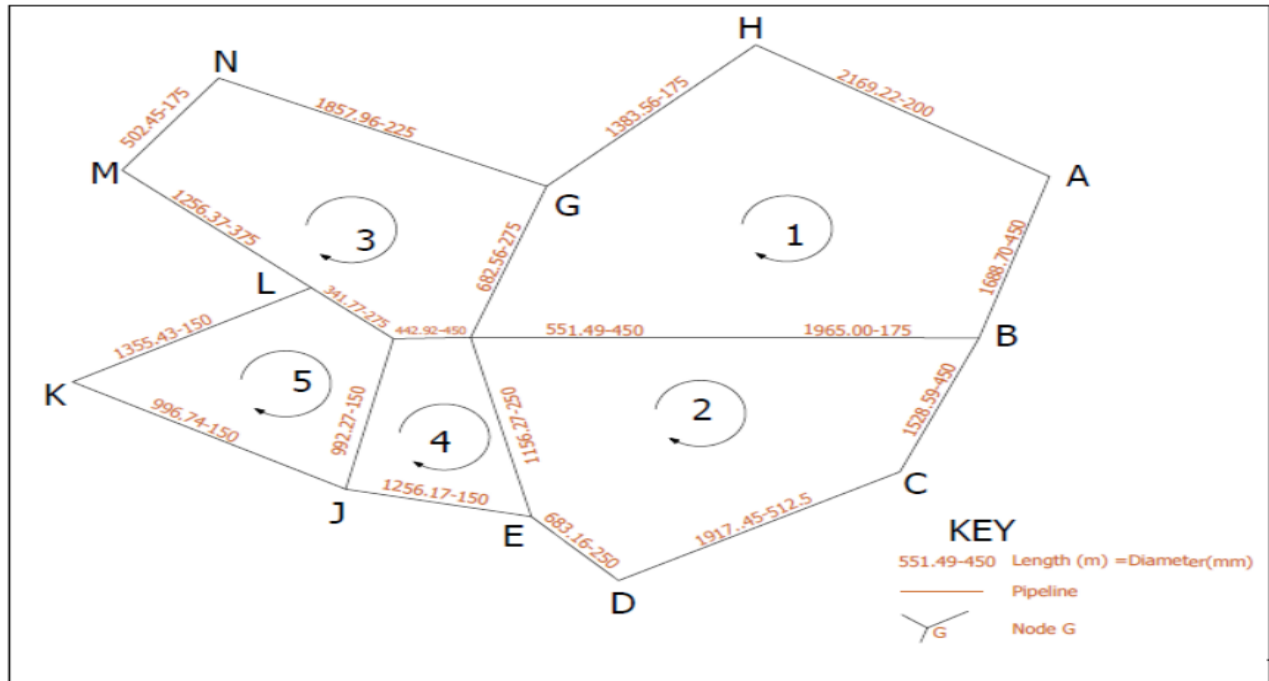


Figure 4 Pipeline layout for the metropolis showing the pipeline dimensions

The assumed flows were then generated such that continuity is satisfied at each node, i.e. the flow to each junction must equal the flow out of junction. There are ten cases (I - X) considered for study, which are based on the location of the service reservoirs. Each of the cases considered are presented in Table 4.

2.2.5 Water Supply Infrastructural Survey

A digital map of the pipe layout for the town was obtained from the Kwara State Water Cooperation along with other information regarding features such as pipe diameter, length, nodal elevation, service reservoir location and height and all other fittings and appurtenances that constitute the distribution system was collected. As presented in Table 1, the total supply system in Ilorin is sourced from the Agba, Asa and Moro Rivers. Reservoirs built on these rivers have a total reservoir storage capacity of about $49.10 \times 10^6 \text{ m}^3$ with total treatment plant at full capacity operation of about $82,276 \text{ m}^3/\text{day}$. The average estimated water demand and the peak demand along pipes is presented in Table 5. The peak demand was assumed as twice the estimated average water demand in line with standard water supply engineering design manuals and guidelines (AWWA, 2005). The distribution system in the metropolis is primarily dictated by street patterns, topography, water

demand and location of treatment and service reservoirs. For Ilorin Metropolis, the pipe network is made up of Asbestos Cement (AC), Cast Iron (CI), Galvanized Iron (GI) and Unplasticized Polyvinyl Chloride (UPVC) pipes ranging from 50mm to 600mm diameter and cover a total distance of about 337.542 km. In recent time, there were additional pipelines ranging from 100mm to 800mm diameter made of D.I. and UPVC which cover a total distance of about 107.87 km to upgrading the system. Out of the total length of the pipelines, 79.02 km are new pipelines either for rising main or distribution network while the remaining length of about 28.85 km were used to replace some of the existing AC pipelines within the township. The population covered by each loop was based on the assumption that the town has an equal population density for all areas. This means that the population of an area is dependent on the area enclosed by the loop. The areas and corresponding population of the loops under consideration has been presented in Table 6, along with the combine pipe lengths. A roughness coefficient of 140 was used for the analysis since the pipes are made of asbestos Cement (Steel and McGhee, 1984; Chupi et al. 2022). Total pipe length for each loop was also determined in order to estimate demand in each of the loop as presented in Figure 5. All the parameters were determined using the available data from KSWC

with additional information through the aid of GIS and google earth map.

Table 3: Areas, Population, Pipes and total length of the Pipes in each Loop, Various demands

Loop	Area (x10 ⁶ m ²)	Population	Pipes	Total length (m)	Average Demand (l/s)	Peak demand (l/s)	Consumption per length (x10 ³ , l/s/m)
1	5.09	45,810	AB, BF, FG, GH, AH	8440.53	63.63	127.26	15.05
2	2.38	21, 420	BC, CD, DE, EF, BF	7603.96	29.75	59.50	7.82
3	1.62	14,580	GF, FI, LI, LM, MN, GN	4924.72	20.25	40.50	8.22
4	1.61	5,490	EF, EJ, IJ, FI	3814.86	7.63	15.26	4.00
5	0.91	8,190	IJ, JK, KL, LI	3662.08	11.38	22.76	6.22
Total		95,490					

Table 4: Various Cases Considered with Reservoirs and Loops used

Case No	I	II	III	IV	V	VI	VII	VIII	IX	X
Reservoir (s) S/No	1	10, 12 and 13	12	13	10	13 and 10	10 and 12	13	12	12
Loop (s) Used	All	All	All	All	All	All	All	1	2	3 and 4

Table 5: Water demand along pipes

Loop	Pipes	Population	Area (m ²)	Total length (m)	Average demand (l/s)	Peak demand (l/s)
1	JK, KP, PQ, JQ	18060	1389.22	6101.26	25.08	50.17
2	KP, KL, LM, MO, OP	13860	1066.14	3487.25	19.25	38.50
3	IJ, IR, LR, KL, JK	17561	1350.84	7095.48	24.39	48.78
4	FI, DF, DE, EN, MN, LM, LR, IR	25385	1952.68	9462.00	35.26	70.51
5	BE, EN, AN, AB	16191	1245.50	6038.85	22.49	44.98
6	BE, BC, CD, DE	19834	1525.69	5950.78	27.55	55.09
7	FG, GH, HI, FI	6030	463.82	4244.86	8.37	16.75

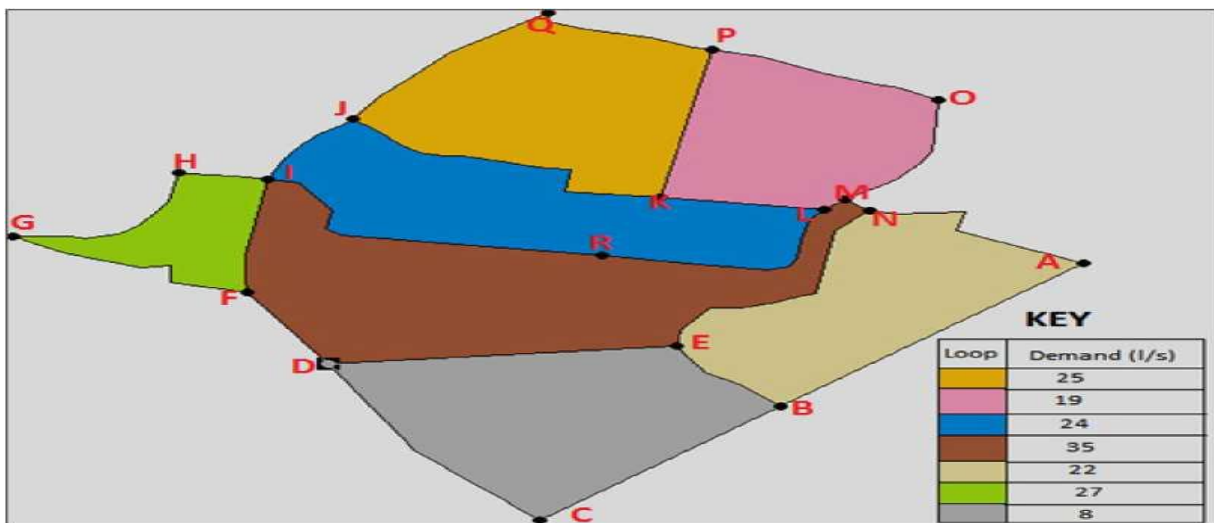


Figure 5 Pipe Network Distribution zone showing Demand Variation

2.2.6 Pressure Simulation and Analysis

Pressure simulation in EPANET 2.2 software involved digitization of network layout and defining of the junctions, pipes, reservoirs and pumps within the EPANET environment. Each junction node was assigned its elevation which were derived from topographic (DEM data) and base water demand, while pipes were assigned lengths, diameters, and roughness coefficient. The main input parameters used include; nodal elevation, demand characteristics, pipe hydraulic properties, and reservoir heads. EPANET uses the same numerical engines as Water CAD and other commercially available software. Several commercial simulation models are available, but in this study EPANET 2.2 was used to perform hydraulic simulation. EPANET's hydraulic simulation model computes hydraulic heads at junctions and flow rates through links for a fixed set of reservoir levels, and water demands over a succession of points in time. The principle of EPANET network analysis is based on the following two conditions (Avesani, et al., 2012; Adeniran and Oyelowo, 2013): the algebraic sum of the pressure drops around a closed loop must be zero, i.e. there can be no discontinuity in pressure and; the flow entering a junction must be equal to the flow leaving the same junction; i.e. the law of continuity must be satisfied. Based upon these two basic principles, the pipe networks are generally solved by the method of successive approximation (Ramalingam et al., 2009; Sil et al., 2012; Uchit et al 2022).

3 Results and Discussion

Before the introduction of new reservoirs, the minimum pressure head was 2.89 m while only one node has pressure head above 84 m. The percentage nodal pressure variation for the various cases considered is presented in Table 6. It was revealed that Case IV has highest percentage total number of nodes with pressure between 25 m and 84 m, with the new reservoirs the minimum pressure is 10 m and the maximum pressure head obtained is 84 m. Case V has the least percentage total number of nodes for the same pressure range (25 m and 84 m), with the new reservoirs the minimum pressure is -47.78 m and the maximum pressure head obtained is 104.97 m. Based on these results the areas with high pressure, would need pressure reducing valves along the

pipeline so as to reduce excessive pressure that might be generated. In case IV there is no negative pressure as observed in Case V. Also for the percentage number of nodes with pressure below 25 m, Case V has the highest value, while Case III has the least value. However, with the percentage number of nodes with pressure greater than 84 m; Cases II, IV, IX and X have none while Cases I, III, V, VI, VII and VIII have with Case III has the highest value.

Table 6: Percentage Nodal Pressure Heads Variation for the various Cases

Case	Below 25 (m)	Between 25 m and 84 m	Above 84 (m)
I	20	73	7
II	40	60	0
III	7	60	33
IV	20	80	0
V	86	13	1
VI	47	47	7
VII	60	33	7
VIII	20	75	5
IX	50	50	0
X	56	44	0

Based on these facts, using case IV to distribute water will be more effective, because it has the highest percentage number of nodes that fall between 25 m and 84 m. Also, about 20% of the total nodes have pressure below 25 m and none above 84 m, which will rule out the possibility of pipe bursting as a result of excessive pressure in the pipeline. Hence it can be said that Case IV has the optimal nodal pressure distribution. However, the minimum residual pressure for pipe network systems pressure varies from one country to another. According to Bhardwaj, (2001) the recommended minimum pressure heads varies between 25 m and 28 m and maximum pressure heads vary between 70 m and 84 m, and some literature like Washington State University Uniform Design Standard recommended 35 m and 140 m as minimum and maximum pressure head respectively. A lower value of residual pressure seems to be economical since the distribution cost will be reduced and excess residual pressure above recommended value could lead to pipe busting. However, 10 m to 84 m pressure head value has emerged based on case IV.

4 Conclusion

Optimizing hydraulic performance and service reservoir siting in Ilorin metropolitan city is a critical step toward achieving sustainable, efficient, and resilient water supply infrastructure. The minimum and the maximum nodal pressures obtained were favorably comparable with the recommended values for satisfactory performance of a water supply pipe network. Based on these facts, using case IV to distribute water will be more effective, because it has the highest percentage number of nodes that fall between 25 m and 84 m. About 20% of the total nodes have pressure below 25 m and none above 84 m, which will rule out the possibility of pipe bursting as a result of excessive pressure in the pipeline. Hence it can be said that Case IV has the optimal nodal pressure distribution. It was concluded that the study provide a suitable model for appropriate selection and location of the service reservoirs based on pressure requirement at demand nodes for municipal water distribution pipe network. This will serve as a guide for proper operation and management of the pipe network distribution system of Ilorin metropolis.

Conflict of Interests

The authors hereby declare and confirm that there are no competing interests associated with the publication of this paper.

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