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Hydraulic analysis of water distribution network in Bauchi metropolis using Epanet 2.0

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Abstract

This research investigates the hydraulic analysis of the water distribution network in Bauchi metropolis, which is characterized by low pressure points affecting access to safe potable water for a large population. The network comprises 97 pipes of various sizes, 72 junctions, 2 tanks, and one source reservoir supplying water. Estimated current and future water demands are 42,856.16 m³/day and 63,214.48 m³/day respectively for the next 20 years. EPANET 2.0 was utilized for analysing and redesigning the system to address these demands. The analysis of the current water distribution network revealed inefficiencies, with 94% of nodes experiencing negative pressure after 4 hours of simulation. Only 8 out of 72 nodes maintained a pressure head above 14 m, falling short of the AWWA's recommended 15-70 m range. Additionally, 39 out of 97 links exceeded the maximum velocity of 3 m/s, and 85 links surpassed the minimum flow rate of 0.3 l/s. The system's average output of 451.76 l/s does not meet the total nodal demand of 726.87 l/s, resulting in a 37.85% shortfall. Expanding the treatment plant to increase reservoir capacity is recommended.

Keywords: Water distribution network, hydraulic analysis, Epanet 2.0, water demand forecasting

Introduction

Water is fundamental to life and health, driving development and public welfare. As living standards rise, water needs increase (Rossman *et al*., 2024) [8]. Access to safe drinking water is a universal human right that should be guaranteed for everyone, regardless of socioeconomic status (Adedeji *et al*., 2022) [2]. Global and national efforts, especially in Bauchi state, aim to ensure this access. A key goal of water supply systems is to deliver safe potable water for domestic, fire, and industrial use (Ahmed *et al*., 2023) [3]. Bauchi metropolis obtains its water supply from Gubi Dam, positioned at latitude 10.42° and longitude 09.88°, with a height of 27 m and a crest length of 3860 m. The dam has a total reservoir capacity of 38.3 million cubic meters. During the rainy season from September to November, the reservoir level rises to a maximum of 557.37 m, then decreases to a minimum of 553 m from December to around June.

Fig 1: Gubi Dam/ Treatment Plant

Location of Study Area

Bauchi is a state in northern Nigeria, with its capital, Bauchi town, located at latitude 10°04′N and longitude 9°09′E. The region experiences a tropical climate, characterized by distinct wet and dry seasons. Bauchi Metropolis covers an area of 36.04 km², with populations of 230,328 and 421,187 recorded in the 1991 and 2006 censuses, respectively. The urban study area extends from Wunti Dada in the south to Inkil in the east, including neighborhoods like GRA, Yelwa, and Bauchi city. An associated image from Google Earknowledge about the hydraulics of the distribution network raises concerns, particularly in areas like Yalwa, where low water pressure results in minimal supply, and Fadaman Mada, where high pressure damages plumbing. These issues necessitate a hydraulic analysis of the water distribution system.

Significance of the Research

Water is essential for human needs and vital for sustainable economic growth and poverty reduction. Its supply and distribution significantly enhance health, education, and overall human development.

Justification of the Research

The research highlights the critical importance of improved water supply for state development. Access to adequate water directly impacts the quality of life and poverty alleviation. Many women and children waste hours daily collecting water from unsafe sources such as open wells and ponds. Clean drinking water is essential for survival and neglecting this need can result in loss of life or disease outbreaks.

Aim and Objectives

Aim of the Research

The research work is aimed at carrying out hydraulic analysis of water distribution network system of Bauchi Metropolis to establish its adequacy or otherwise and to recommend upgrade where necessary.

Objectives

The objectives of the research work are:

1. To appraise the existing situation of water distribution network system.
2. To estimate the existing water demand.
3. To estimate the future water Demand
4. To re-design the water distributions network system to meet the current and future demand.

Scope of the Research

This research work is limited to hydraulic analysis of water distribution network system of Bauchi metropolis in terms of water demand, pressure head, flow rate and velocity.

Literature Review

1. Introduction

A water supply system transports treated water to consumers through a distribution network, which comprises pipes, storage facilities, pumping mains, and valves. This system must deliver adequate water for domestic, commercial, and fire protection needs. Historically, humans manually fetched water, limiting usage for essential activities. Modern needs for large volumes of water for various purposes, such as showering and irrigation, necessitate these advanced systems (Abubakar, *et al.* 2024) [1].

2. Existing Water Distribution of Bauchi Metropolis

A study by Ahmed *et al.* (2023) [3] indicates that Bauchi metropolis faces challenges in water supply. To address this, they developed a software using Visual Basic for a computer-based water distribution system, which allows for control from a dashboard. The local water supply is provided intermittently at specific times during the day, and the current distribution relies on a gravity system from a tank at Warinji Hill. The system includes two circular concrete tanks and a network of pipes with diameters ranging from 150 mm to 800 mm.

Fig 2.1: A 500 mm diameter Pipe

Fig 2.2: A 150 mm diameter pipe

3. Consideration in Designing of water Supply

Water Demand

In designing water supply systems, key considerations include the population's water demand, necessary fire flow for safety, and proximity to water sources. Water demand can be categorized into residential, commercial, industrial, and public uses. Residential use pertains to households, commercial use to businesses, industrial use to manufacturing, and public use to governmental facilities. Larger industries often rely on non-public sources, as seen in Bauchi metropolis. Domestic water needs are at least 115 liters per day per household, with studies showing varying requirements, such as 135 liters per day in Auchi and a WHO recommendation of 80 liters per day for Bauchi State.

Population Data

Population data is crucial for designing an effective water distribution network, with both current and future demographics in mind. A 2022 WHO study indicates that the state population stands at 5,421,273, including 456,990 in Bauchi metropolis. The population density has nearly doubled since 1991, highlighting significant growth in urban areas, with an average increase of 3.4% per year.

Population Forecasting

To accurately predict future population, it is essential to understand the factors influencing population growth: birth, death, and migration. These factors complicate forecasting, making it imprecise and challenging, particularly for engineers assessing social influences. Typically, reliance shifts to mathematical models and graphical solutions based on historical population data (Rossman *et al*. 2024) [8]. Population forecasting is crucial for designing water distribution systems to meet both current and future demands.

Arithmetic Method

The arithmetic method of forecasting population is more suitable when the rate of growth level off and the relationship represented in equation 2.1 follows

$$\frac{dp}{dt} = k_a \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.2.1$$

Where k_a is arithmetic growth constant. Integrating equation 2.1 above, give the population as a function of time; and equation 2.2 gives the value of the arithmetic constant (Abdullahi *et al* 2013).

$$k_a = \frac{P_2 - P_1}{t_2 - t_2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.2.2$$

Substituting the limits in equation 2.2, the predicted population will be obtained using equation 2.3 below:

$$P_{(t)} = P_o + k_a t \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.2.3$$

where $P_{(t)}$ is the forecasted population, P_0 is the population at t=0

Geometric Method

The geometric method is best used when the rate of population change is equivalent to the population at a given time. That is; population tend to grow at varying rate, therefore population, P tend to increase geometrically according to the relationshown in equation 2.4 below;

$$\frac{dp}{dt} = k_g P \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.2.4$$

where k_g is a growth constant. Integrating the equation gives equation 2.5 as a function of time;

$$P(t) = P_0 e^{kgt} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 2.5$$

Where P_0 is the population at some initial time.

Graphical Method

The graphical method uses the previous population record, the past years population is plotted against time, graphical extension to the future year lead to population of the future year.

Pipe network Geometry

The water distribution networks have mainly the following three types of configurations:

Branched or tree like configuration

These types of pipe network are a distribution system having no loops such a network is commonly used for rural water supply. The simplest branched network is a radial network consisting of several distribution mains emerging out from a common input point as shown in figure 2.3

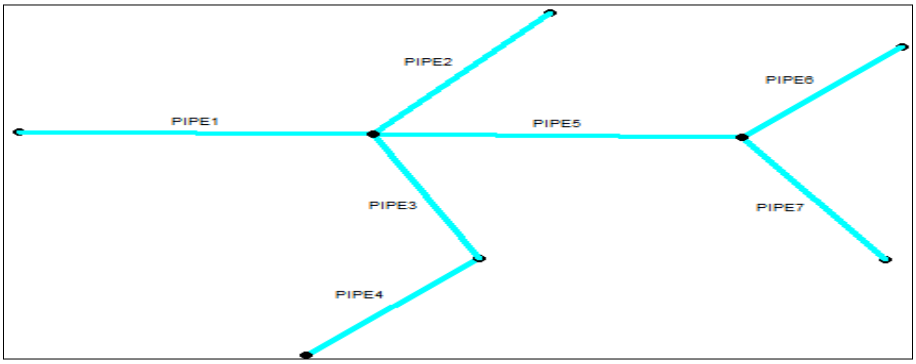

Fig 2.3: A Branched network of Pipe

Looped Network configuration

This is pipe network in which there are one or more closed loops. A typical looped network is shown in Fig 2.4. Looped networks are preferred from the reliability point of view, if one or more pipeline is closed for repair, water can still reach the consumer by circulation route, this feature is absent in a branched network.

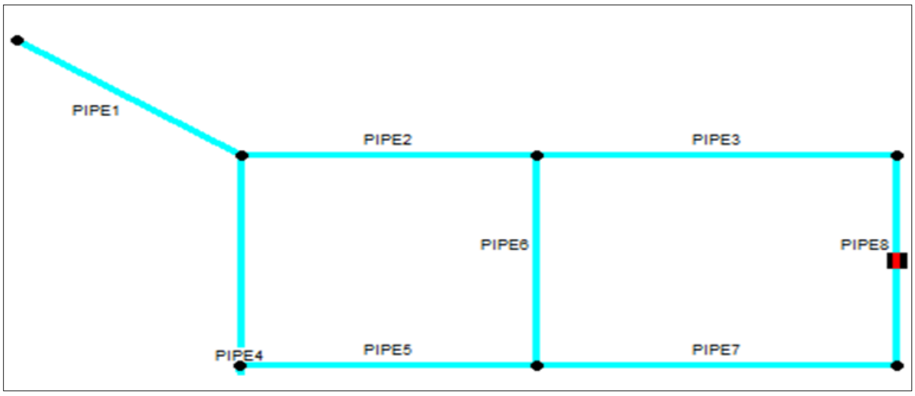

Fig 2.4: Looped Networks

Branched and Looped Configuration

This type of configuration is the combination of the two type of network explain above.

Pipe Network Analysis

A pipe network is analysed to determine nodal pressure head and link discharges, which vary with time leading to continuous changes. The analysis focuses on worst-case discharge scenarios that could cause low-pressure heads in certain areas. Additionally, network analysis identifies deficiencies for remedial measures, making it essential for the effective operation and maintenance of water supply systems.

Method of Network Analysis

There are different methods of pipe network analysis which include the following:

Hardy cross method

Adedeji (2022) [2] developed a systematic tabular process for analyzing lopped pipe networks with specific inflows and outflows at the University of Illinois. This method is predicated on the fundamental equations of flow continuity and head loss.

1. The sum of inflow and out flow at a node should be equal

$$\sum Qi = q_j \dots\dots\dots\dots\dots.\dots\dots\dots\dots\dots\dots..2.6$$

$$for\ all\ nodes\ j = 1{,}2{,}3 \dots\dots\dots\dots\dots\dots\dots\dots j_l$$

Where Q is the discharge in pipe I meeting at node (junction) j and q_j is nodal withdrawal at node j.

2. The algebraic sum of the head loss in a loop must be equal to zero.

$$\sum KiQi|Qi| = 0 \dots\dots\dots\dots\dots\dots\dots\dots\dots.\dots\dots\dots\dots\dots\dots.2.7$$

$$for\ all\ loops, k = 1{,}2{,}3, \dots\dots\dots\dots\dots.\ k_l$$

$$K_i = \frac{8f_iL_i}{\pi^2 qD_i^5} \dots\dots\dots\dots\dots..\dots\dots\dots\dots\dots\dots\dots\dots..2.8$$

$$where\ i = pipe\ link\ number\ to\ be\ summed\ up\ in\ the\ loop\ k$$

Newton –Raphson Method

The Newton-Raphson Method is a numerical technique used for analyzing pipe networks by evaluating the entire system simultaneously, unlike the Hardy-Cross method. It effectively solves nonlinear equations defining flow in pipes, focusing on three main aspects: unknown flow rates in pipes, head at junctions, and corrective flow rates around loops. The procedure requires an initial guess to adjust flow rates while satisfying energy equations without disrupting continuity. Steps in the method involve drawing tangents at chosen points to improve root estimates iteratively. This approach ensures accurate flow adjustments in closed-loop systems.

$$f'(x_i) = \tan\theta i = \frac{f_{(xi-0)}}{x_{(i-xi+1)}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 2.1$$

This gives,

$$x_{i-1} = x_1 - \frac{f_{xi}}{f' x_{(xi)}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 2.2$$

Figure 2.5 Newton- Raphson method iterations

Computer Application Method

Following the introduction of window-based packages by Microsoft and Apple Macintosh, developers began creating programming languages such as FORTRAN, BASIC, COBOL, and C++. These languages enable complex calculations efficiently, making iterative tasks easier for engineers and scientists. A wide range of computer programs for hydraulic analysis and water system simulation is now available, from handheld calculators for small systems to sophisticated software for personal computers that can analyze extensive networks with numerous pipes.

Review of Modeling Software for Piped Distribution Networks

In recent years, the number of software applications for analyzing pipe distribution networks has significantly increased in both commercial and public sectors. This proliferation complicates the selection process for systems managers and designers as they strive to find the most suitable software for local needs, leading some to suggest that the choice resembles a random selection process.
Table 2.1 gives an overview of resent software.
TABLE 2.1 Examples of Distribution System Modeling Software
UNICEF (2023) [9].

AquaNet

AquaNet, launched in 1992 and utilized in 17 countries, features a graphical user interface (GUI) and a computational engine that can operate independently. It models various components such as pipes, pumps, and tanks, and is noted for its reliability, speed, and compatibility across operating systems. The upcoming version 2.x, named PPNS, combines AquaNet with PipeNet, introducing a Java-based GUI for broader OS compatibility. Its computational engine supports integration with other systems like GIS and allows text file input.

Archimed

Archimede is a Windows-based software for engineers and distribution network companies in water and gas sectors. Developed by proteos.r. l since 1986, it simulates steady-state flow conditions in pressurized networks. The user-friendly interface features a graphical editor that allows customizable visualization of fluid networks. ARCHIMEDE employs an algorithm to solve complex equations, calculating energy losses in pipes and flow at various nodes using real field data, all while providing clear graphical and numerical results.

Eraclito

Eraclito is a software package designed for hydraulic and technical management of fluid networks, compatible with Windows 95 and NT. Developed by PROTEOS.r.l., it allows users to simulate pressurized fluid networks (such as water and gas) and open channels under various flow conditions. ERACLITO features a user-friendly graphical interface for data input and quick viewing of calculation results in numeric and graphic formats. It includes a customizable Report Maker and allows for data export in formats compatible with common office software.

H2onet/H2omap

H2onet / H2omap is a GIS-enabled software designed for comprehensive modelling, analysis, design, rehabilitation, and optimization of water distribution systems. Launched in 1996, it offers fast and reliable hydraulic modelling, water quality evaluation, leakage management, and real-time simulations, among other functionalities. Its advanced optimization features support automated network drawing, pump scheduling, and optimal design. Developed with Map Object technology in an open-architecture environment, it serves as a robust decision-support tool for infrastructure planning and management.

The program integrates network modelling with GIS software, aiding in diverse applications such as master planning, emergency response, and asset management. It features a user-friendly interface compatible with native GIS data formats, supports multiple themes, and provides an open architecture for data manipulation. Additionally, it offers comprehensive hydraulic and water quality analyses, Genetic Algorithm optimization, and advanced graphing, reporting, and querying tools.

Netis

The Netis software package is a network design tool for creating new systems and reinforcing existing ones. It employs formal optimization techniques for analyzing least-cost pipe sizing based on user-specified service levels. Specifically designed for intermittent water distribution systems, NETIS addresses the challenges posed by systems that supply water for only a few hours daily, which is common in developing countries.

NETIS consists of four main components:

1. **Preliminary design model:** Calculation of equity equation and calculation of water tower storage capacity.

2. **Demand model:** Using queuing theory and reservoir routing, the model forecasts the end-user demand profile (intensity and distribution of usage). It includes a secondary network model establishing pressure dependent outflow functions for a single node (primary node) from a group of nodes (secondary network).

3. **Network charging model:** Uses a pressure head iterative method that simulates the charging up of the network prior to pressurised flow.

4. **Modified Network Analysis Method:** Program that incorporates pressure dependent demand during pressurised flow.

NETIS, developed in Visual C/C++, enables users to edit input data files for various models and run a simulator that presents results graphically, including on network schematics. Development is ongoing.

Pipe 2000

Pipe2000 is a versatile hydraulic modelling program for both steady state and transient analysis, widely utilized in municipal, rural, and industrial applications including fire protection and irrigation systems. It features kypipe2000, which incorporates hydraulic and water quality modelling, utilizing the trusted kypipe 4 engine, recognized as an industry standard for 30 years with extensive verification, including nuclear applications. epanet is also used for water quality analysis within the system.

Standard pipe2000 node elements encompass various components such as junctions, tanks, pumps, and hydrants. Its advanced modelling capabilities enable direct calculations of operational parameters, system curve development, and optimized calibration. The user-friendly graphical environment facilitates model development and data entry. Additionally, pipe2000 features powerful data exchange tools for interfacing with applications like CAD and GIS, incorporating modules for ArcView, AutoCAD, and Excel.

Wadisosa

The program is an evolution of the wadiso model from Colorado State University, enhanced by GLS Engineering Software for optimization, usability, and speed. Known as WADISOSA, it combines steady state simulation, time simulation, optimization, and water quality analysis with graphical data displays. This multi-purpose tool for water engineers features modules for designing, calibrating, modeling, analyzing, and managing distribution systems, incorporating elements like tanks, reservoirs, and demand nodes with five demand scenarios. Additional functionalities include integration with a high-speed CAD system, synchronized editing across multiple spreadsheet tables, and results exportable in HTM or XLS formats.

WaterCAD 5.0

Haestad Methods has been a key player in water distribution modelling since the release of WaterCAD (CYBERNET) over a decade ago, continually enhancing network modelling technology. WaterCAD supports the analysis of potable water networks, sewage mains, fire protection systems, and well pumps, facilitating the calibration of extensive distribution networks and operational studies. The latest version offers features such as an advanced graphical editor, animated contouring, scenario management, and connectivity with GIS and databases, enabling both steady-state analysis and extended period simulations.

WaterCAD® 5.0 introduces significant upgrades, featuring new hydraulic capabilities such as Active Topology Alternatives (ATA), Automated Calibration, Logical Rule-Based Controls, and Variable-Speed Pumping (VSP). The software also offers a stand-alone interface with a CAD-style drag-and-drop design and compatibility for DXF background maps, along with an AutoCAD interface for direct network creation.

EPANET 2.0

EPANET 2.0 is a Windows-based program designed for simulating hydraulic and water quality behaviours in pressurized pipe networks. It includes components such as pipes, nodes, pumps, valves, and storage tanks. The software tracks water flow, node pressure, tank water levels, and chemical concentrations throughout the simulation period, allowing for water age and source tracing. EPANET provides an integrated environment for editing data, running simulations, and displaying results through color-coded maps, data tables, time series graphs, and contour plots.

EPANET, developed by the U.S. Environmental Protection Agency's National Risk Management Research Laboratory, aids water utilities in enhancing water quality through distribution systems. It facilitates the design of sampling programs, analyses disinfectant loss and by-products, and assesses consumer exposure. Additionally, it supports the evaluation of strategies to improve quality, such as optimizing source utilization in multisource systems, adjusting pumping schedules to minimize water age, employing booster disinfection, and planning targeted pipe maintenance.

EPANET aids in planning and enhancing hydraulic performance through activities like pipe, pump, and valve placement, energy minimization, fire flow analysis, vulnerability studies, and operator training. While it lacks direct connections to external CAD, GIS, or databases, it can import data via ASCII text files and export analysis results in various formats. Additionally, observed data can be compared with simulation outcomes for calibration, and the EPANET 2.0 Programmer's Toolkit offers developers access to its computational engine for customized applications, such as automated calibration and optimization studies.

EPANET's computational engine has been further adapted in various commercial products (DHI, Haestad Methods, KYPIPE, MW-Soft)

EPANET contains a state-of-the-art hydraulic analysis engine that includes the following capabilities:

1. Places no limit on the size of the network that can be analysed
2. computes friction headloss using the Hazen-Williams, Darcy-

Weisbach, Chezy or Manning formulas

1. Includes minor head losses for bends, fittings, etc.
2. Models constant or variable speed pumps
3. Computes pumping energy and cost.
4. Models various types of valves including shutoff, check, and pressure regulating and flow control valves.
5. Allows storage tanks to have any shape (i.e., diameter can vary with height).
6. Considers multiple demand categories at nodes, each with its own pattern of time variation Models pressure-dependent flow issuing from emitters (sprinkler heads)

In addition to hydraulic modelling, EPANET 2.0 provides the following water quality modelling capabilities:

a. Models the movement of a non-reactive tracer material through the network over time.
b. Models the movement and fate of a reactive material as it grows (e.g., a disinfection by-product) or decays (e.g., chlorine residual) with time.
c. Models the age of water throughout a network.
d. Tracks the percent of flow from a given node reaching all other nodes over time.
e. Models reactions both in the bulk flow and at the pipe wall.
f. Uses n-th order kinetics to model reactions in the bulk flow.
g. Uses zero or first order kinetics to model reactions at the pipe wall.

Steps in Using EPANET

One typically carries out the following steps when using EPANET to model a water distribution network system:

1. Draw a network representation of your distribution system or import a basic description of the network placed in a text file.
2. Edit the properties of the objects that make up the system'
3. Edit the properties of the objects that make up the system
4. Describe how the system is operated.
5. Select a set of analysis options.
6. Run a hydraulic/water quality analysis
7. View the results of the analysis (Rossman, 2000).

Material & Method

Data Collection

The data collected relied mainly on secondary information. In order to carry out the research work the following information were obtained;

1. Population Data from National Population Commission, Bauchi. (1991 and 2006 census figures).
2. Water supply records from Bauchi State Water Board.
3. General Layout map of Bauchi Metropolis pipe network from Bauchi Water Board.
4. Elevations of various point and
5. Photogrammetric image of the study area from Google Earth.

Data Analysis

The Analysis is based on the total water requirement for an area. For Bauchi Metropolis the present population was projected to 20 years design.

Formula used in calculating head loss in pipe which include:

1. Hazen-Williams
2. Darcy-Weisbach

Each formula measures pipe roughness differently, so switching formula might require that all pipe roughness coefficient be updated (Rossman, 2000).

For the purpose of this research work, Hazen-Williams Headloss formula was selected.

Design Criteria

Population Data

The population of the metropolis was obtained from the National Population Commission, Bauchi office, from which the future population was determined.

Design population

This forms a major criterion as it is design to serve both present and future needs of the metropolis. The water requirement was determined by obtaining the water needs of the population in the area projected to a 20 years design period.

Population Projection

20-year design population was forecasted using the arithmetic method. This method is employed for this research work because is the method used by National Population Commission in Nigeria.

The population was projected using equation 3.1 and 3.2 as follows:

$$P_{(t)} = P_0 + k_{at} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..3.1$$

P_t= Projected population
P_0= Population at some initial time
$K_{a=}$ is an arithmetic growth constant.

The population of Bauchi metropolis according to 1991 and 2006 census figures was 230,328 and 421,187 respectively (National Population Commission Bauchi, 2015).
Using the relationship in equation 3.2 below:

$$K_a = \frac{(P_2 - P_1)}{(t_2 - t_1)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

where P_2 is taken to be population in 2006 and P_1 population in 1991, t_2 and t_1 there corresponding period, form the above census figure Ka is found to be:

$$K_a = \frac{(421{,}187 - 230{,}328)}{(2006 - 1991)} = 12{,}723.93$$

The current Population will be thus:

$$P_{(2015)} = 421{,}187 + (12{,}723.93 * 9) = 535{,}702$$

Therefore, the population of the metropolis in the next 20 years (2035) using equation 3.1 above will be:

$$P_{(2035)} = 535{,}702 + (12{,}723.93 * 20) = 790{,}181$$

Water Demand

Water demand is crucial in designing water supply systems for populations. Design should be based on demand projected for 20 years ahead, as recommended by AWWA (1992). It is calculated by multiplying the predicted population by per-capita water demand to obtain the design flow rate.

Variation in Demand

Water demand fluctuates seasonally and daily, with a maximum daily demand factor of 1.8 used in the design (Velon & Jonson 1993).

Method of Network Distribution Analysis

The analysis aims to obtain link discharge on all main pipes, determine nodal pressure head, and conduct extended period simulation of the Bauchi water supply network system, utilizing Epanet 2.0 software for this purpose.
Additional software used are:

1. AutoCAD was used to draw dimensions. The software was used to draw the general layout of the pipe network.
2. Goggle Earth is used to produce photographic image of locations; it also gives the altitude of any point of interest.

Result and Discussion

Population Forecast

From the Arithmetic method of population forecasting as described in chapter three, the Arithmetic method was employed for this research. The population of Bauchi metropolis was projected to 2035. Table 4.1 below shows the projection at ten years interval from 2006 to 2035.

Table 4.1: Population forecast result

Year	2006	2015	2025	2035
Population	421,187	535,702	662,942	790,181

Water use Estimation

The study area falls under the category of urban settlement and according to Nigerian Federal Ministry of Water Resources (2021) [7], 80 lpcd was considered.
The water demand is evaluated by multiplying consumption rate per head per day with the estimated population; the result is shown in Table 4.2.

Table 4.2: Water use Estimation of Bauchi Metropolis

Year	Population	Consumption litres/head/day	Water Demand (litres/day)
2015(current)	535,702	80	42,856,160
2025	662,942	80	53,035,360
2035	790,181	80	63,214,480

Estimations of Nodal Demand

In order to obtain the nodal demand, the following are considered:

1. **Population Demand:** In this case the population of the area is multiplied by the consumption rate.

2. **Fire Demand:** For the purpose of fire outbreak, large quantity of water is required, therefore, provision is made in the water work to supply sufficient quantity of water or keep as reserve in the water mains for this purpose. In this case 10% of the population demand is added as fire demand (World Bank 2023) [12].

3. **Minor Losses:** A provision of 5% is made for minor losses. This is to take care of losses at fittings, valves and bends (Adedeji, *et al.* 2022) [2].

4. **Unaccounted for Water (UFW):** Unaccounted for water contribute significantly to water losses in distribution network. Unaccounted-for-water (UFW) refers to water lost in the network of pipelines between the water treatment plants and consumers as a result of leakage and other reasons. Often, the lack of maintenance causes the network to deteriorate over time. UFW can range between 10% and 30%. The study area for this work is located in Bauchi State and 31.54% is allowed for as UFW (Nigerian Federal Ministry of Water Resources, 2021) [7].

The current and future nodal drawn off is evaluated as presented in Table 4.3.

Table 4.3: Nodal drawn off

Year	Daily Demand (l/d)	Demand (l/s)	Fire demand 10% (l/s)	Minor loss 5% (l/s)	UFW 31.54% (l/s)	Total nodal drawn off (l/s)	Nodal drawn off(l/s)
2015	42,856,160.00	496.02	49.60	24.80	156.44	726.87	10.10
2035	63,214,480.00	731.65	73.16	36.58	230.76	1,072.16	13.75

Currently, Bauchi state water distribution system produce an average of 451.76 l/s as against the current nodal drawn off of 726.87 l/s this shows a short of 37.85% (WHO, 2022) [13]

Distribution Network Parameters

After creating the network on the EPANET platform, the next step involves assigning network parameters such as pipe lengths, diameters, roughness coefficients (Hazen-Williams), and nodal elevations. These fundamental parameters are essential for future simulations based on the projected flow. The data on current and future demands were utilized to analyze the Bauchi metropolis distribution system, with results presented and discussed.

Nodal Pressure Head Situations

The result of pressure head in meter for each of the node in the distribution system for an extended period simulation of 4 hour is as shown in Figure 4.1

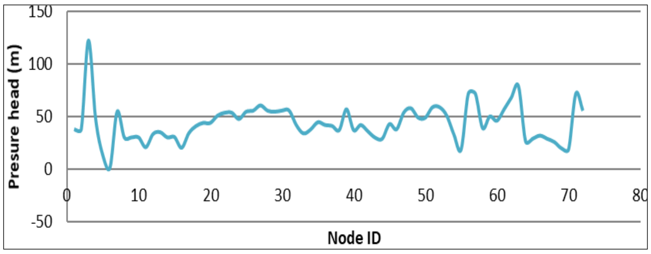

Fig 4.1: Result of pressure head at nodes at 4 hours

Epanet 2.0 was utilized to design the water supply system in the study area, focusing on pressure head, flow quantities, and head loss in pipelines. Recommended minimum pressure heads range from 25 m to 28 m, while maximums vary between 70 m and 84 m, with lower residual pressures potentially reducing distribution costs. However, a 4-hour supply is inadequate for urban areas like Bauchi, evidenced by a simulation indicating negative pressure in 58 of 72 nodes. AWWA recommends a pressure head between 15 m and 70 m, while WHO identifies 4 m to 14 m as insufficient for many appliances.

The simulation results after 4 hours show that out of 72 nodes, 2 have pressure heads between 0 m to 14 m at Gombe road gate, 16 range from 17 m to 30 m at various locations including Abubakar Tafawa Balewa Housing estate, Tashan Babaye, Ran Gate, and Gwallameji, 53 nodes have pressure heads from 31 m to 80 m, primarily at Fadaman Mada, and 1 node, Node 3 at Gubi, has a pressure head of 122.48 m.

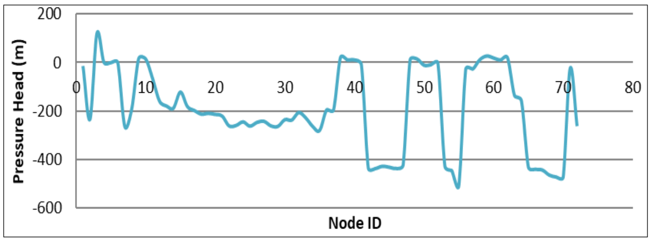

Fig 4.2: Result of pressure head at nodes at 5 hours

The pressure in the network is generally low, indicating inefficiency. Negative pressure situations should be avoided as they can allow fecal organisms and human viruses from groundwater to enter the pipeline, potentially leading to waterborne diseases (WHO, 2022).

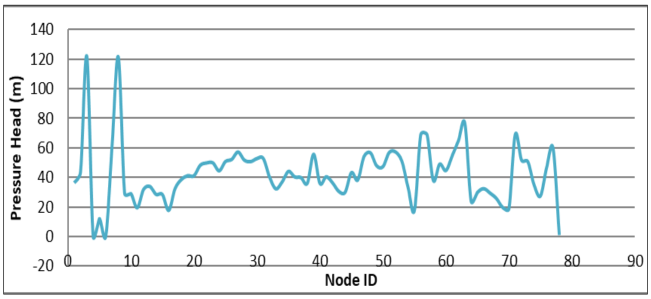

Fig 4.3: Design future pressure head at 12 Hour

In the proposed future design with a new reservoir, analysis shows that out of 78 Nodes, 4 have a pressure head below 11.73 m, while 74 exceed 25 m, indicating a good overall performance within recommended minimum values, with a maximum pressure head of 121.68 m at Gubi (Ahmed, 2023) [3].

Water flow rate and velocity in Pipes

The flow rate and velocity of the current and future situation as analyse by the EPANET is as presented in Figure 4.4, Figure 4.5 and Figure 4.6.

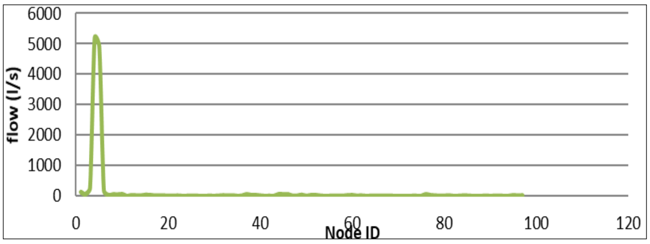

Fig 4.4: Result of flow in Pipe at 4 hours

The flow and subsequent head losses in a water distribution system is at maximum when the pressure head is minimum and the pressure head is at maximum when the flow rate and the subsequent head losses in the pipe line are at minimum.

Design and layout of water distribution system in G12/ASI code compliance document set out acceptable minimum flow rate in pipe at 0.3 l/s while the Velocity must not exceed 3 m/s (IWA, 2022) [6].

Conclusions

In this study, the Bauchi metropolis water distribution network was analyzed using EPANET 2.0. Current water production averages 451.76 l/s, while nodal withdrawal is 726.87 l/s, indicating a shortage of 37.85%. The system can maintain adequate pressure for only 4 hours, with 68 of 72 nodes experiencing negative pressure under extended simulation. Velocity measurements show 39 of 97 links exceed the recommended maximum of 3 m/s, and flow rates for 85 links are above the minimum of 0.3 l/s after 4 hours. A redesign was conducted to meet current and future demands of 726.87 l/s and 1,072.16 l/s, respectively, demonstrating adequacy in simulations of 4, 5, and 12 hours, with 74 out of 78 nodes achieving more than 25 m pressure head. This work provides insights for effective operation and management of the water distribution network.

Recommendations

Based on the result of the analysis carried out the following recommendations have been made:

1. Expansion of the existing treatment plant to boost the capacity of the reservoir so as to meet the current (2015) and future (2035) demand of 726.87 l/s and 1,072.16 l/s respectively.
2. Construction of additional tank at Game village to supply the south lower zone.
3. Provision of 1000 mm diameters pipeline from the treatment plan to an additional tank to be sited at mechanic village hill along Wunti Dada road.
4. Provide and lay 300 mm diameter pipeline as an extension in the following location:
   a. Federal low-cost to Gwallameji
   b. Railway station to Inkil axis
   c. Ibrahim Bako up to Turum

This will ensure adequate supply of water to the affected area as they are now fast-growing areas.

In addition, the following are also recommended

1. A strong and well equip maintenance unit should be put in place to ensure good maintenance practice so as to avoid losses of water.
2. The end cap should be checked at least once in a month to ensure the removal of sediment accumulation.
3. Individuals should be encouraged to participate in the water distribution process; this will promote ownership and reduce the cost of maintenance.

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