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DESIGN OF A CLEAN WATER DISTRIBUTION NETWORK SYSTEM IN JUBA CITY, CENTRAL EQUATORIA STATE, SOUTH SUDAN

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ABSTRACT

Juba City, situated about 457 meters above sea level, features flat terrain near the River Nile and is surrounded by gentle hills. The city has an area of 52 Km^2 with a population of 500,000 people. This thesis aims to project the population for the year 2033, design a clean water distribution network system. Key data used includes historical population figures, topographic information, facility layouts, water source flow rates, and cost estimates. The analysis involved the use of Microsoft Excel, Google Earth Pro, QGIS, Civil 3D, EPACAD, and AutoCAD, with the main distribution system design carried out using EPANET 2.2 software. The projected population by 2033 is 669,735 people, with an estimated clean water demand of 2.288 m^3/s. Water loss was calculated at 0.343 m^3/s. The proposed network is designed as a dead-end system, consisting of 3,783 nodes and a total pipeline length of 218,862 meters. The distribution system uses HDPE PN 16 pipes, specifically 6-inch pipes totaling 127,823.8 meters and 4-inch pipes totaling 91,038.3 meters. The total budget for the project is estimated at Rp. 140.3 billion with 7 months implementation period.

Keywords: Design, Distribution network, EPANET 2.2 software.

1. INTRODUCTION

South Sudan faces its fair share of significant water challenges especially concerning clean drinking water systems for urban cores such as Juba. Such a system must guarantee the secure delivery of safe, portable, affordable water to households, businesses, and institutions while minimizing the risks of contamination. Core components set up of a meaningful system of pipelines and opened when giving as coordinated water strain and balance. Proper water treatment plants are essential for eliminating toxins and microbes, ensuring that the water meets the health standards. The local contexts like limited infrastructure, seasonal rainfall patterns, high-cost materials, etc also need to be factored in by the system. Along with government support and support from donors to obtain fundings and resources, community engagement and capacity building are keys to maintaining the network. These systems must also be managed efficiently, which can mean implementing sustainable practices such as recycling and preventing leaks to guarantee long-term resilience and accessibility. (Jube Gore et al., 2020)

The demand for clean drinking water is increasing day by day with corresponding increase in population. This continuously increasing demand can be fulfilled by designing efficient water distribution networks based on advance computing systems which include modern hydraulic modelling and designing software. In order to develop adequate service, these systems must be carefully planned, designed, operated, and maintained. Design of distribution network for continuous water supply can be easily achieved with the help of software EPANET which is used for water distribution network design and management. The present study will discuss the design of clean water distribution network system using a tool or software which perform the simulation of hydraulic and water quality behavior within the pressurized network of pipes called Epanet.(Rezagama et al., 2020)

2. METHOD

The study began by calculating the water demand of Juba city based on the ten years data from 2013 to 2023 respectively and projected to the design horizon year of 2033.

Study Area

The design of water distribution network system will be done in Juba City. Juba city is the largest and the capital city of the Republic of South Sudan. Geographically, Juba city is located at the longitude of 4˚51’0’’ North of the equator and a latitude of 31˚37’0’’ East. The study covers the whole Juba city with an area of about 52 square kilometers and having a population of about 500,000 people in 2025. It has an elevation of 457 meters above sea level

Data Collection

The following are the data used in this study:
1. Population data for 2013-2023 of Juba city
2. Topographic data of the area (elevation and coordinate)
3. Facilities data
4. Source of flow
5. List of unit prices of the material

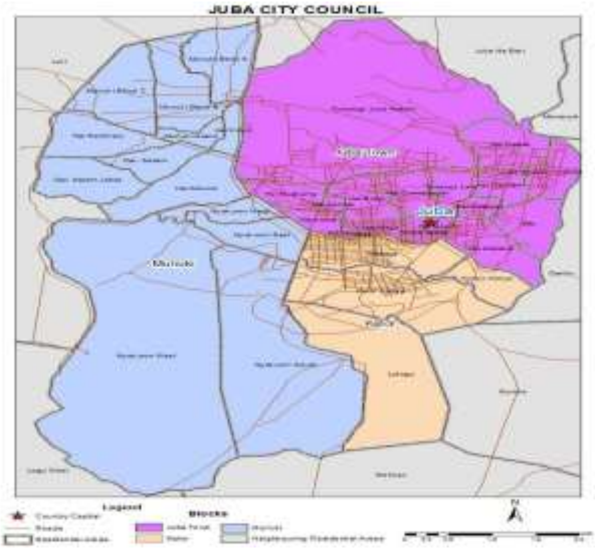

Figure 1. Map of Juba city

Data processing

1. Population was predicted using calculations by geometric method, arithmetic method, and the exponential method [5]. The clean water distribution network system was prepared for the period of 10 years from using the population of 2013-2023 [3].
2. The standard deviation values are compared to test the suitability of the population prediction method.
3. Needs for the clean water are calculated.
4. The clean water distribution network system was then designed and analysed using EPANET 2.2 software.
5. The budget plan for the was also estiametd
6. The project scheduling was made to ensures it is completed on time.

3. RESULTS AND DISCUSSION

Population prediction and water demand analysis

The amount of water demand for Juba city in 2033 was calculated as (197,706 m^3/day or 2.288 m^3/s), based on the projected population of 669,735 people and a per capita consumption rate of 170 liters/person/day.

The calculated amount of water loss is 0.343 m^3/s.

Using Epanet 2.2 software, the network is designed as a dead-End system comprising of 3,783 junctions with total length of the pipe of 218,862 meters.

After the hydraulic modelling was made using Eapnet 2.2 software, analysis of the nodal demand, pressure distribution, head values, flow rate, velocities, and head loss was carried out. For example, in p191 there is a nodal demand of 1.04 liters/second, head value of 31.44 meters, pressure of 143.96 meters, flow rate of 1256.54 Galon per minute, velocity of 0.60 m/s and the head loss of 1.34 meters.

The total estimated cost is Rp.140.3 billion with 7 months implementation period.

Table 1. Population of Juba City from 2013-2023

YEAR	TOTAL POPULATION
2013	293000
2014	307000
2015	321000
2016	336000
2017	352000
2018	369000
2019	386000
2020	403000
2021	421000
2022	440000
2023	459000

Calculation for the projected population in 2033

Annual population growth calculation

The population growth calculation starts in 2014

$$r1 = \frac{307000 - 293000}{293000} x\ 100\%$$

$$r1 = 4.78\%$$

Population prediction using the three methods

1. Arithmetic method

$$\mathbf{Pt = P_0.(1 + n.r)}$$

2. Geometric method

    $$Pt = P_0.(1 + r)^n$$

3. Exponential method

    $$Pt = P_0.e^{rn}$$

Table 2. Population prediction

Years	Arithmetic (Population)	Geometric (Population)	Exponential (Population)
2024	480073	480073	480565
2025	501147	502114	503143
2026	522220	525167	526781
2027	543294	549279	551530
2028	564367	574497	577442
2029	585441	600873	604572
2030	606514	628460	632976
2031	627588	657314	662714
2032	648661	687492	693850
2033	669735	719056	726448

Standard deviation (sd)

1. Arithmetic method

Here is the arithmetic method for calculating the standard deviation.

$$sd = \frac{\sqrt{\Sigma(X_i - Xr)^2}}{n-1}$$

Table 4. Arithmetic table

Year	Total Population	$(Xi - Xr)^2$
2024	480073	8992847104
2025	501147	5440117384
2026	522220	2775570094
2027	543294	999205234
2028	564367	111022804
2029	585441	111022804
2030	606514	999205234
2031	627588	2775570094
2032	648661	5440117384
2033	669735	8992847104
Mean	574904	36637525239

The calculated standard deviation (sd) is 21267.70

Determining the population in the planning year

The population prediction in 2033 is taken from the arithmetic method because it has the smallest value of the standard deviation which is 21267.70
Hence, the population prediction in the year 2033 is 669735 people.

Domestic requirement (Qd)

Total population in 2033 = 669,735 people.
Standard basic needs = 170 liters/person/day
Qd = 669,735 x 170 = 1,318 m^3/s

Non-domestic requirement (Qnd)

Non-domestic requirement (Qnd) = 30% of the domestic requirement (Qd)
Qnd = 0.3 x 113,854,950 liters/day = 0,395 m^3/s

Determine the needs for public hydrants (Qhu)

Needs for public hydrant (Qhu) = 30 liters/person/day x 669,735 people
Qhu = 30 x 669,735 = 0,233 m^3/s

Average daily requirement (Qrt)

Qrt = Qd + Qnd
Qrt = 113,854,950 + 34,156,485 = 148011435 liters/day or 1,713 m^3/s

Maximum daily requirement

In this case the maximum factor chosen is 1.20
Maximum daily requirement = Qrt x 1.20 = 2.056 m^3/s

Determine the planned water loss (Qha)

The planned water loss is calculated as the 20% of the average daily requirement
Therefore;
Qha = 20% x Qrt = 0.343 m^3/s

Peak hour requirement (Qpeak)

In this case the peak hour factor is 2.
Qpeak = Qrt x 2 (peak hour factor) = 128011435 x 2 = 3.426 m^3/s

Planned discharge of clean water needs in 2033 (Qr)

The planned discharge of clean water needs in the year 2033 is:
Qr = Qd + Qnd + Qhu + Qha
= 113,854,950 + 34,156,485 + 20,092,050 + 29,602,287
= 197705772 liters/day or 2,288 m^3/s

Water usage fluctuations

Water usage fluctuation is the water demand variation over time due to factors such as the time of the day, day of the week, season, and the user behavior.

Maximum daily water usage (Qmax)

Maximum daily water usage (Qmax) = planned discharge (Qr) x 1.15, where 1.15 is the maximum daily factor.
Therefore;
Qmax = Qr x 1.15 (maximum daily factor)
= 197705772 liters/day x 1.15
= 2.632 m^3/s

Water usage at maximum hour

Water usage at maximum hour = planned discharge (Qr) x 1.5, where 1.5 is the maximum hour factor.
= 197705772 liters/day x 1.5
= 3.432 m^3/s

Reservoir capacity

The reservoir capacity generally ranges from 15-20% of the total water production or discharge (Qmax).
Reservoir capacity = 20% x Qmax
= 0.2 x 227361637,8 liters/day
= 12.631 m^3/s

Dependable discharge

Dependable discharge refers to the minimum water flow rate that can be reliably supplied from the river under normal condition over time.

Figure 3. River cross-section 1

Cross Sectional Area 1
A = Depth x Width

Width (m) = 300
Depth (m) =5
Flow area = 300 x 5 = 1500 m^2

Perimeter

P = b + 2h
= 300 + 2*5
= 310 m

Figure 4. River cross-section 2

Cross Sectional Area 2

$$A = B \times H + Z \times H^2$$

Bottom width (m) = 200
Depth (m) = 5
Side slope (z) = 2
Flow area = $(200 \times 5) + 2 \times 5^2$
= 1050 m^2

Perimeter

$$P = b + 2\sqrt{z \times h^2 + h^2}$$
$$= 200 + 2\sqrt{2 \times 5^2 + 5^2}$$
$$= 217.320 \text{ m}$$

Average flow area $= \frac{\text{Flow area 1} + \text{Flow area 2}}{2}$
$= \frac{1500+1050}{2}$
= 1275 m2

Average perimeter $= \frac{\text{Perimeter 1} + \text{Perimter 2}}{2}$
$= \frac{310+217}{2}$
= 263.5 m

Hydraulic radius, R $= \frac{\text{Area}}{\text{Perimeter}}$
R $= \frac{1275}{264}$
= 4.839 m

River slope $= \frac{\Delta H}{L}$
$= \frac{\text{River base elevation difference}}{\text{Distance between cross section}}$
$= \frac{463-456}{455}$
= 0.0154

Flow rate (using manning equation)
n manning = 0.035 (for winding, sloping, and grassy land)

Flow rate (V) $= \frac{1}{0.035} \times 1.83^{\frac{2}{3}} \times 0.0154^{\frac{1}{2}}$
= 3.96 m/s

Discharge = flow rate x area
Q = V x A
= 3.96 x 1275
= 5049 m^3/s

Comparison of the River Nile discharge and the reservoir capacity
5049 m^3/s: 12,631 m^3/s

$\frac{12.631}{5049}$ x 100% = 0.3%

Distribution Network Design using Epanet

The elevation data of the study area is imported to the AutoCAD Civil 3D and the file of the area will be obtained showing various features and elevation data. Using EPACAD software, the AutoCAD Civil 3D file is then converted to an EPANET file. After obtaining the network layout in the EPANET, various parameters such as units, notations, formulas, scales, and etc are set.

After the network layout in the EPANET, the base demand and the pipe diameter are entered then the network is run and the length, demand, head, pressure, flow, velocity, and the head loss are obtained.

Demand model analysis

The demand model analysis in Epanet determines how the water usage at every node or junction is represented during the simulation.

$$D = Df\left(\frac{P-P_0}{P_f-P_0}\right)^n$$

Pressure

Pressure refers to the force exerted by the water inside the pipe, typically measured in meters of water column or Pascals.

$$P = \gamma(H - z)$$

Flow

Flow represents the volume of water passing through a pipe per unit time, usually measured in liters per second (L/s), cubic meters per hours (m3/h) or gallon per minute (GPM).

$$\Sigma Q_{in} - \Sigma Q_{out} = D$$

Velocity

Velocity is the rate at which water flows through the pipe, typically expressed in meters per second.

$$v = \frac{Q}{A} = \frac{4Q}{\pi D^2}$$

Head loss

Head loss refers to the reduction in the total energy (head) as water flows through the network, primarily due to friction within the pipes and minor losses from fittings and bends.

$$h_f = 10.67 \times \frac{L \times Q^{1.852}}{C^{1.852} \times D^{4.87}}$$

4. CONCLUSION

The clean water distribution system designed for Juba City efficiently meets projected 2033 demands. The dead-end network layout, designed with EPANET 2.2, accommodates the population with sustainable flow, minimal loss, and sufficient pressure. The implementation budget is Rp.140.3 billion and will take 210 days. The design ensures sustainable and reliable water supply with minimal impact on River Nile resources.

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Figure 8. Pipe ID and Diameter

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