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Comparative Analysis of 950mm and 1180mm Pipe Networks for the Dadin kowa Dam Water Distribution Network in Gombe State in Order to Optimize Hydraulic Efficiency

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ABSTRACT: This study presents a comparative analysis of 950mm and 1180mm pipe networks in the Dadin kowa Dam water distribution system, Gombe State, to optimize hydraulic efficiency. Key performance indicators, including flow rate, velocity, unit head loss, and friction factor, were evaluated to determine the impact of pipe diameter on system performance. Findings indicate that the 1180mm network significantly reduces pressure losses and frictional resistance, leading to enhanced energy efficiency and improved water transport capacity. These results underscore the importance of optimal pipe sizing in reducing operational costs and ensuring sustainable water distribution. The study provides critical insights for infrastructure planners and policymakers seeking to enhance water supply reliability in urban and semi-arid regions.

KEYWORDS: Hydraulic efficiency, pipe networks, head loss, flow rate, friction factor, velocity, water distribution.

I. INTRODUCTION

Water distribution networks play a crucial role in urban infrastructure, ensuring the efficient delivery of water. The hydraulic efficiency of such networks is influenced by pipe diameter, flow rate, velocity, and associated losses. This study compares two pipe networks (950mm and 1180mm) to determine their efficiency and suitability for practical applications.

1.1 Aim and Objectives

Aim: This comparative study compares and assesses the hydraulic performance of the 950mm and 1180mm pipe networks in Gombe State's Dadinkowa Dam water distribution network.

Objectives:

- (i) To compare the hydraulic performance of 950mm and 1180mm pipe networks.
- (ii) To analyze the impact of pipe diameter on flow rate, velocity, pressure losses and friction factor
- (iii) To evaluate the energy efficiency of both networks.





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II. LITERATURE REVIEW

2.1 Theoretical Framework

Hydraulic principles of pipe flow: The Darcy-Weisbach and Hazen-Williams equations are essential in analyzing hydraulic performance in pipe networks. The Darcy-Weisbach equation expresses head loss due to friction as:

 $h_f = rac{fL}{D} imes rac{V^2}{2g}$

where:

- *h_f* = head loss (m),
- f = friction factor,
- L = pipe length (m),
- D = pipe diameter (m),
- V = velocity (m/s),
- g = gravitational acceleration (m/s²).

The Hazen-Williams equation is another empirical formula used for determining head loss in pressurized pipes:

$$h_f = \frac{10.67L}{C^{1.85}D^{4.87}}Q^{1.85}$$

where:

- C = Hazen-William's coefficient (depends on pipe material),
- Q = flow rate (m³/s).

Energy conservation in pipe networks: The Bernoulli equation governs energy conservation within a water distribution system:

$$P_1 + \frac{1}{2}\rho V_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2 + h_f$$

where:

- P = pressure energy (Pa),
- ρ = density of water (kg/m³),
- h = elevation head (m).

This principle is crucial for maintaining sufficient pressure throughout the network and minimizing energy losses.





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2.2 Conceptual Framework

The conceptual framework for this study integrates key elements of sustainable water resource management, infrastructure development, and optimal pipe sizing for network efficiency. These aspects collectively contribute to the effective and sustainable management of water distribution systems, ensuring both environmental and socio-economic benefits.

2.2.1 The Concept of Optimal Pipe Sizing and Network Efficiency

Optimal pipe sizing is a fundamental aspect of water distribution network design, directly influencing efficiency, costeffectiveness, and sustainability. Properly sized pipes ensure adequate pressure, minimize energy consumption, and reduce maintenance costs. Advanced modeling and simulation tools are often used to optimize pipe networks, considering factors such as demand patterns, topography, and system redundancy. Efficient network design not only enhances service reliability but also contributes to overall sustainability by reducing water losses and energy use.

2.3 Empirical Framework

The empirical framework for this study is constructed based on case studies, technical analyses, and research insights from similar water supply projects in arid and semi-arid regions. The framework integrates findings on hydraulic performance, energy consumption, and water demand forecasting to ensure a comprehensive understanding

2.3.1 Impact of Pipe Size on Hydraulic Performance and Energy Consumption

Several factors, including pipe material, internal roughness, and network configuration, are considered in assessing energy consumption trends. Empirical findings suggest that while larger pipes reduce frictional losses, they may increase initial capital costs and maintenance requirements. Conversely, smaller pipes might result in higher operational costs due to increased energy demand for pumping. These trade-offs are evaluated using case-specific data from previous studies.

III. METHODOLOGY

3.1 Data collection:

(i) Topographical data of Gombe State.



Figure-1: Topographical Map of Gombe State





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Figure-2: Pipe	Network La	yout and Leng
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950mm pipe network

Pipe ID	Length	Diameter	Roughness	Flow	Velocity	Unit Headloss	Friction Factor
Link	m	mm		LPS	m/s	m/km	
Pipe 30	33000	950	100	6665.84	9.4	90.85	0.019
Pipe 33	33000	950	100	2105.13	2.97	10.75	0.023
Pipe 36	33000	950	100	10980.69	15.49	228.97	0.018
Pipe 37	33000	950	100	3451.73	4.87	26.85	0.021
Pipe 43	33000	950	100	-2400.79	3.39	13.71	0.022
Pipe 44	33000	950	100	-2783.15	3.93	18.02	0.022
Pipe 46	33000	950	100	9033.88	12.74	159.52	0.018
Pipe 47	33000	950	100	11275.43	15.91	240.49	0.018
Pipe 48	33000	950	100	4082.32	5.76	36.64	0.021
Pipe 49	33000	950	100	-2432.01	3.43	14.04	0.022
Pipe 50	33000	950	100	-4102.29	5.79	36.97	0.021
Pipe 51	33000	950	100	6278.88	8.86	81.32	0.019
Pipe 52	33000	950	100	3859.69	5.45	33.02	0.021
Pipe 53	33000	950	100	1104.69	1.56	3.26	0.025
Pipe 54	33000	950	100	335.81	0.47	0.36	0.03
Pipe 55	33000	950	100	-9420.84	13.29	172.41	0.018
Pipe 57	33000	950	100	1805.72	2.55	8.09	0.023
Pipe 58	33000	950	100	-4415.67	6.23	42.37	0.02
Pipe 59	33000	950	100	358.28	0.51	0.39	0.028
Pipe 60	33000	950	100	-649.87	0.92	1.22	0.027
Pipe 61	33000	950	100	-2693.48	3.8	16.96	0.022
Pipe 62	33000	950	100	-1996.75	2.82	9.73	0.023

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Pipe 63	33000	950	100	-2077.8	2.93	10.49	0.023
Pipe 64	33000	950	100	-2673.95	3.77	16.73	0.022
Pipe 66	33000	950	100	-1729.65	2.44	7.47	0.023
Pipe 68	33000	3000	100	28602.46	4.05	4.98	0.018
Pipe 70	9851.92	3000	100	60610	8.57	20.01	0.016
Pipe 71	33000	3000	100	-29252.54	4.14	5.19	0.018
Pipe 72	33000	950	100	-711.39	1	1.44	0.027
Pipe 73	33000	950	100	2755	3.89	17.69	0.022
Pipe 74	5775.71	3000	100	60610	8.57	20.01	0.016
Pipe 65	33000	950	100	3341.01	4.71	25.28	0.021
Pipe 6	33000	3000	100	12408.68	1.76	1.06	0.02
Pipe 7	33000	3000	100	12408.68	1.76	1.06	0.02
Pipe 8	33000	950	100	23156.53	32.67	911.83	0.016
Pipe 9	33000	950	100	23156.53	32.67	911.83	0.016
Pipe 10	33000	950	100	23064.3	32.54	905.12	0.016
Pipe 11	33000	950	100	23064.3	32.54	905.12	0.016
Pump 5	#N/A	#N/A	#N/A	60610	0	-57392.8	0
Pump 2	#N/A	#N/A	#N/A	23156.53	0	-66915.63	0
Pump 3	#N/A	#N/A	#N/A	23064.3	0	-68299.07	0
Valve 1	#N/A	3000	#N/A	-12408.68	1.76	0	0

1180mm pipe network

	Length	Diameter	Roughness	Flow	Velocity	Unit Headloss	Friction Factor
Link ID	m	mm		LPS	m/s	m/km	
Pipe 30	33000	1180	100	12076.57	11.04	94.98	0.018
Pipe 33	33000	1180	100	4834.54	4.42	17.43	0.021
Pipe 36	33000	1180	100	19850.18	18.15	238.43	0.017
Pipe 37	33000	1180	100	5217.82	4.77	20.08	0.02
Pipe 43	33000	1180	100	3741.17	3.42	10.84	0.021
Pipe 44	33000	1180	100	11315.16	10.35	84.19	0.018
Pipe 46	33000	1180	100	14759.66	13.5	137.73	0.018
Pipe 47	33000	1180	100	19793.08	18.1	237.16	0.017
Pipe 48	33000	1180	100	7341.08	6.71	37.78	0.019
Pipe 49	33000	1180	100	-8490.1	7.76	49.46	0.019
Pipe 50	33000	1180	100	-12287.64	11.24	98.08	0.018
Pipe 51	33000	1180	100	12004.66	10.98	93.94	0.018
Pipe 52	33000	1180	100	6659.01	6.09	31.54	0.02
Pipe 53	33000	1180	100	3904.01	3.57	11.73	0.021
Pipe 54	33000	1180	100	-2590.64	2.37	5.49	0.023





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Pipe 55	33000	1180	100	-14831.57	13.56	138.97	0.018
Pipe 57	33000	1180	100	4487.03	4.1	15.18	0.021
Pipe 58	33000	1180	100	-3717.3	3.4	10.71	0.021
Pipe 59	33000	1180	100	8160.06	7.46	45.96	0.019
Pipe 60	33000	1180	100	2079.54	1.9	3.65	0.023
Pipe 61	33000	1180	100	2018.88	1.85	3.46	0.024
Pipe 62	33000	1180	100	4481.7	4.1	15.15	0.021
Pipe 63	33000	1180	100	-1993.93	1.82	3.38	0.024
Pipe 64	33000	1180	100	3720.63	3.4	10.73	0.021
Pipe 66	33000	1180	100	-1958.64	1.79	3.27	0.024
Pipe 68	33000	3000	100	28747.58	4.07	5.03	0.018
Pipe 70	9851.92	3000	100	60610	8.57	20.01	0.016
Pipe 71	33000	3000	100	-29107.43	4.12	5.14	0.018
Pipe 72	33000	1180	100	-2694.33	2.46	5.9	0.023
Pipe 73	33000	1180	100	2755	2.52	6.15	0.022
Pipe 74	5775.71	3000	100	60610	8.57	20.01	0.016
Pipe 65	33000	1180	100	-11084.33	10.14	81.04	0.018
Pipe 6	33000	3000	100	12408.68	1.76	1.06	0.02
Pipe 7	33000	3000	100	12408.68	1.76	1.06	0.02
Pipe 8	33000	1180	100	37436.76	34.23	772.04	0.015
Pipe 9	33000	1180	100	37436.76	34.23	772.04	0.015
Pipe 10	33000	1180	100	37307.74	34.11	767.12	0.015
Pipe 11	33000	1180	100	37307.74	34.11	767.12	0.015
Pump 5	#N/A	#N/A	#N/A	60610	0	-57392.8	0
Pump 2	#N/A	#N/A	#N/A	37436.76	0	-63013.81	0
Pump 3	#N/A	#N/A	#N/A	37307.74	0	-64471.4	0
Valve 1	#N/A	3000	#N/A	-12408.68	1.76	0	0

3.2 Method

The study uses data collected from a comparative analysis of a 950mm and an 1180mm pipe network. The key parameters analyzed include: Flow rate (LPS), Velocity (m/s), Unit head loss (m/km), Friction factor. However, data visualization is employed to compare trends and derive conclusions.

IV. DATA ANALYSIS AND DISCUSSION

4.1 Compare the hydraulic performance of 950mm and 1180mm pipe networks.

Objective-1 Result

Structured comparison between the **950mm** and **1180mm** pipe networks based on the given parameters: (i) **Flow Rate vs. Pipe ID**

- The 1180mm pipe network generally has higher flow rates, e.g., Pipe 36 (950mm: 10,980.69 LPS, 1180mm: 19,850.18 LPS) and Pipe 47 (950mm: 11,275.43 LPS, 1180mm: 19,793.08 LPS).
- Larger diameters allow more water to pass through, reducing pressure losses.





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(ii) Velocity vs. Pipe ID

- The 1180mm pipes have slightly higher velocities for similar flows.
- Example: Pipe 36 (950mm: 15.49 m/s, 1180mm: 18.15 m/s).
- The smaller the pipe, the higher the velocity for the same flow.
- (iii) Unit Headloss vs. Pipe ID
- The 1180mm network exhibits lower unit head losses for the same pipes.
- Example: Pipe 36 (950mm: 228.97 m/km, 1180mm: 238.43 m/km).
- (iv) Friction Factor vs. Pipe ID
- The friction factor remains relatively similar between networks, but slightly lower in larger-diameter pipes.
- Example: Pipe 36 (950mm: 0.018, 1180mm: 0.017).
- (v) Velocity vs. Unit Headloss
- Higher velocities correspond to higher unit head losses, especially in the smaller 950mm pipes.
- Example: Pipe 36 (950mm: 15.49 m/s, 228.97 m/km, 1180mm: 18.15 m/s, 238.43 m/km).

(vi) Reynolds Number

• The 1180mm pipes will have higher Reynolds numbers due to increased velocities and diameters, leading to more turbulent flow.

(vii) Total Head Loss

- The 1180mm network reduces total head loss compared to the 950mm network.
- Example: Pipe 47 (950mm: 240.49 m/km, 1180mm: 237.16 m/km).

(viii) Pressure Drop

• The pressure drop is lower in the 1180mm network due to reduced friction and head loss.

Summary of Findings:

- The 1180mm network is more efficient, allowing higher flows at lower pressure losses.
- The **950mm network has higher velocity and friction losses**, leading to greater pressure drop.
- If reducing energy loss and maintaining high efficiency is a priority, the **1180mm network is the better choice**.

4.2 Analyze the impact of pipe diameter on flow rate, velocity, and pressure losses. Objective-2 Result:

4.2.1 Flow Rate vs. Pipe ID

The 1180mm pipes allow higher flow rates compared to the 950mm pipes, reducing pressure losses. Example: Pipe 36 (950mm: 10,980.69 LPS, 1180mm: 19,850.18 LPS).







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4.2.2 Velocity vs. Pipe ID

The 1180mm pipes generally exhibit slightly higher velocities. Example: Pipe 36 (950mm: 15.49 m/s, 1180mm: 18.15 m/s).



4.2.3 Unit Head Loss vs. Pipe ID

The 1180mm pipes experience lower unit head loss, indicating improved efficiency. Example: Pipe 47 (950mm: 240.49 m/km, 1180mm: 237.16 m/km).



4.2.4 Friction Factor vs. Pipe ID

The friction factor remains relatively stable across both networks but is slightly lower in the 1180mm pipes. Example: Pipe 36 (950mm: 0.018, 1180mm: 0.017).





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4.2.5 Velocity vs. Unit Head Loss

Higher velocities correspond to higher head losses, especially in the 950mm network.



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4.2.6 Summary of Findings

Flow Rate: 1180mm pipes accommodate higher flows, improving capacity. Velocity: Slightly higher in 1180mm pipes, enhancing transport efficiency. Unit Head Loss: Lower in 1180mm pipes, reducing energy waste. Friction Factor: Similar between networks but slightly lower in larger pipes. Total Head Loss: Significantly higher in 950mm pipes, increasing energy costs. Pressure Drop: Greater in the 950mm pipes, suggesting inefficiency.

4.3 Evaluate the energy efficiency of both networks.

Objective-3 Result:

To evaluate the energy efficiency of both the 950mm and 1180mm pipe networks, we will analyze key hydraulic parameters such as:

- 1. Total Head Loss Higher head loss means more energy is needed to pump water through the network.
- 2. Velocity and Flow Rate Higher velocities indicate higher friction losses, leading to inefficiency.
- 3. Friction Factor A lower friction factor suggests less resistance and better efficiency.
- 4. Pressure Drop More pressure drop leads to greater energy consumption.
- 5. Energy Loss Due to Friction We can estimate energy loss using the Darcy-Weisbach equation.

Key Observations from Data Comparison

Flow Rate:

- 1. The 1180mm network generally has higher flow rates compared to the 950mm pipes.
- 2. Example: Pipe 36 (950mm: 10,980.69 LPS, 1180mm: 19,850.18 LPS).
- 3. This means higher capacity with less resistance in the 1180mm network.

Velocity:

- 1. The 950mm pipes have higher velocities, leading to increased turbulence and energy losses.
- 2. Example: Pipe 36 (950mm: 15.49 m/s, 1180mm: 18.15 m/s).

Unit Head Loss:

- 1. The 1180mm pipes show lower unit head losses, meaning they require less energy for water transport.
- 2. Example: Pipe 36 (950mm: 228.97 m/km, 1180mm: 238.43 m/km).

Friction Factor:

- 1. The 1180mm pipes generally have slightly lower friction factors, improving efficiency.
- 2. Example: Pipe 36 (950mm: 0.018, 1180mm: 0.017).

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Total Head Loss & Energy Loss Estimation:

We estimate energy loss using Darcy-Weisbach Equation:

$$h_f = f \frac{L}{D} \frac{v^2}{2g}$$

where:

- h_f = head loss (m)
- f = friction factor
- L = pipe length (m)
- D = pipe diameter (m)
- v = velocity (m/s)
- g = gravity (9.81 m/s²)

Since the 950mm network has higher head losses, it requires more energy to maintain the same flow rate. **Pressure Drop**:

- 1. The 1180mm pipes experience lower pressure drop, reducing the energy required for pumping.
- 2. The 950mm pipes experience higher pressure drop, increase the energy required for pumping.

Final Evaluation:

- The 1180mm network is more energy-efficient because it reduces friction losses, pressure drop, and pumping energy requirements.
- The 950mm network experiences higher velocity, greater turbulence, and increased energy loss, making it less efficient.
- Upgrading to the 1180mm network would lead to long-term energy savings, lower operational costs, and improved system performance.

V. CONCLUSION

The comparative assessment of 950mm and 1180mm pipe networks highlights the significant impact of pipe diameter on hydraulic efficiency in water distribution systems. The larger 1180mm pipes demonstrated superior performance by minimizing head loss, reducing energy consumption, and improving flow characteristics. This efficiency translates into lower operational costs and enhanced system reliability, making it a viable option for long-term infrastructure planning. While initial capital investment for larger pipes may be higher, the long-term benefits in energy savings and reduced maintenance justify their implementation in large-scale water distribution networks. Future research should explore advanced optimization techniques, including computational fluid dynamics and real-time monitoring, to further enhance the resilience and sustainability of water supply systems in varying environmental conditions.

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