The Role of Pipeline Route Selection in Clean Water Distribution to Address Drought in Kupang Regency

Abstract

Drought remains a significant challenge in meeting the clean water needs of communities in Kupang Regency. The construction of Raknamo Dam is expected to serve as a primary water source; however, the effectiveness of water distribution largely depends on proper pipeline network planning, particularly in selecting an appropriate route. This study aims to analyze the influence of pipeline route selection on the performance of clean water distribution systems. A descriptive-comparative approach was employed by evaluating three alternative routes based on pipeline length, elevation differences, and potential flow energy losses (*head loss*). The results indicate that the shortest route does not necessarily provide the best performance, as significant elevation changes can increase energy losses and reduce flow stability. In contrast, routes that follow the natural terrain contours tend to produce more stable and efficient water distribution. Therefore, pipeline route selection that considers topographical conditions and hydraulic aspects plays a crucial role in supporting effective clean water distribution systems in drought-prone areas.

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1. Introduction

The availability of clean water is one of the most essential requirements for supporting community welfare, environmental health, and regional development. However, not all regions have adequate access to clean water resources, particularly areas characterized by dry climatic conditions and relatively low rainfall. Such conditions often result in difficulties in meeting domestic water demands as well as supporting productive economic activities [1].

Kupang Regency is one of the regions in East Nusa Tenggara Province that frequently experiences drought, especially during the prolonged dry season. Limited surface water resources and the uneven distribution of available water supplies have caused many communities to face challenges in obtaining a sustainable supply of clean water. These conditions highlight the need for an effective water supply system capable of delivering water to service areas efficiently and reliably [2].

As part of efforts to improve water availability, the government has developed Raknamo Dam as a strategic water resource for supporting community needs. The presence of the dam provides considerable potential for enhancing clean water supply services throughout Kupang Regency. Nevertheless, the success of water provision depends not only on the availability of water resources but also on the ability of the distribution system to deliver water from the source to the designated service areas [3].

One of the primary challenges in water distribution systems lies in pipeline network planning. Pipeline route selection is a critical factor that directly influences the effectiveness of water delivery. Inappropriate route selection may result in increased energy losses, reduced flow pressure, and higher construction and operational costs. Therefore, route planning must consider various technical factors to ensure optimal system performance [4].

Based on preliminary observations conducted by the research group, several alternative pipeline routes can be identified between Raknamo Dam and the intended service areas. These alternatives exhibit different topographical characteristics, resulting in variations in route length and elevation profiles. Such differences may significantly affect the hydraulic performance of the distribution system. Routes with substantial elevation changes, for example, may experience greater energy losses compared to routes that follow more gradual terrain profiles.

In addition to hydraulic considerations, pipeline route selection is closely related to economic and construction aspects. Excessively long routes may increase material requirements and project costs, while routes crossing difficult terrain may complicate construction activities and future maintenance operations. Consequently, a balance between technical efficiency, economic feasibility, and operational practicality is required when selecting the most suitable route [5].

This study aims to evaluate several alternative pipeline routes for distributing clean water from Raknamo Dam to service areas in Kupang Regency. The evaluation is based on technical parameters including route length, elevation differences, and potential energy losses. The findings are expected to provide insights into the importance of pipeline route selection in improving the effectiveness of clean water distribution systems, particularly in regions that are vulnerable to drought.

2. Materials and Methods

This study utilizes data obtained from observations and analyses conducted by the research group. The data include information on regional elevation, pipeline route length, and topographical conditions surrounding Raknamo Dam and the proposed service areas. These data were used to evaluate several alternative pipeline routes that could potentially be implemented in the clean water distribution system of Kupang Regency.

Topographical data were employed to describe the terrain conditions along the proposed pipeline alignments. This information is important because elevation differences can significantly affect flow pressure, energy losses, and the overall efficiency of water distribution. In addition, route length data were used to estimate pipeline material requirements and the level of construction complexity associated with each route alternative [6].

The analysis was conducted using a descriptive-comparative approach by comparing several pipeline route alternatives based on predetermined technical parameters. This method was selected because it provides a clear understanding of the advantages and limitations of each route and serves as a practical basis for identifying the most suitable alignment under existing field conditions.

The research procedure was carried out through the following stages:

1) Route Identification

Three alternative pipeline routes were identified based on topographical maps and field observations:

- Route A (Shortest Route)
- Route B (Contour-Following Route)
- Route C (Combined Route)

2) Data Processing

Each route was analyzed using the following technical parameters:

- Pipeline Length (L)
- Elevation Difference (Δh)
- Estimated Energy Loss (Head Loss)

3) Technical Analysis

Energy loss calculations were performed using simplified hydraulic approaches commonly applied in pipeline system design, such as the Hazen–Williams or Darcy–Weisbach equations, depending on the method adopted during the academic course. These approaches provide a basic assessment of hydraulic performance and allow comparisons among the alternative routes [7], [8].

4) Evaluation

Each route was evaluated according to several criteria:

- Flow Efficiency
- Distribution Stability
- Ease of Construction

The evaluation results were subsequently used to determine the most suitable pipeline route for supporting clean water distribution from Raknamo Dam to the designated service areas. This method was selected because it provides a practical representation of field conditions while still offering a sufficient technical basis for decision-making in pipeline route planning.

3. Results

This section presents the results of the analysis conducted on the three alternative pipeline routes identified in the previous stage. The analysis focuses on the comparison of key technical parameters and the interpretation of the performance of each route in supporting clean water distribution. The evaluation was carried out by considering route length, elevation differences, and potential energy losses that may affect the efficiency of water delivery from Raknamo Dam to the designated service areas.

In general, the three route alternatives exhibit different characteristics due to variations in topographical conditions. These differences influence hydraulic performance and may affect the overall effectiveness of the distribution system. Therefore, a comprehensive assessment of each route is required to identify its advantages and limitations before determining the most suitable alignment.

3.1 Pipeline Route Analysis Results

Based on the route identification and data processing stages, several key findings were obtained:

- Route A has the shortest pipeline length, resulting in lower material requirements; however, it is characterized by relatively large elevation differences.
- Route B follows the natural terrain contours and has a longer route length, but experiences smaller elevation changes, contributing to more stable flow conditions.
- Route C represents a combination of the previous two alternatives, with moderate route length and elevation variations.

These characteristics indicate that each route possesses distinct advantages and disadvantages depending on the evaluation criteria applied. A shorter route may reduce material requirements and initial construction costs, but it does not necessarily provide the most favorable hydraulic performance. Conversely, a longer route may offer better flow stability if elevation changes are minimized.

The analysis also reveals that topographical conditions significantly influence the performance of the water distribution system. Large elevation differences can increase energy losses during water conveyance, while routes that follow terrain contours tend to provide more uniform pressure distribution throughout the network. Consequently, route selection should be based on multiple technical considerations rather than a single parameter.

Furthermore, the findings suggest that pipeline route optimization requires a balance between hydraulic efficiency, construction feasibility, and operational reliability. A route that performs well in one aspect may not necessarily be the most suitable option when all relevant factors are considered simultaneously.

Overall, the results indicate that pipeline route selection should not be determined solely by route length. Instead, a combination of route length, elevation profile, and potential head loss should serve as the primary basis for selecting the most appropriate alternative to support clean water distribution in Kupang Regency.

3.2 Clean Water Distribution System Diagram

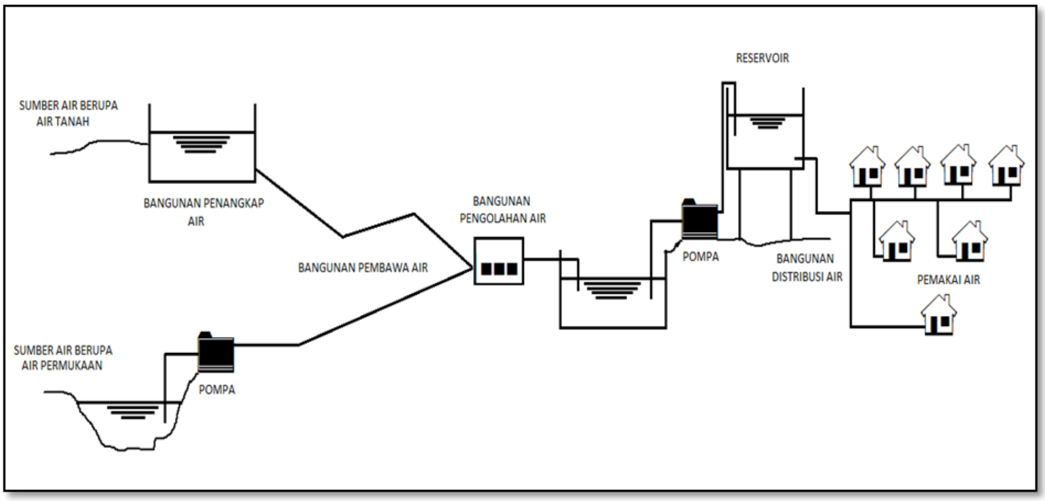

Figure 1. Schematic of the Clean Water Distribution System from the Water Source to the Service Area

Figure 1 illustrates the general configuration of a clean water distribution system consisting of a water source, intake structure, transmission facilities, water treatment units, reservoirs, pumps, and pipeline networks that convey water to the service area. Water originating from the primary source is first collected and transported to the treatment facility before being stored temporarily in a reservoir.

Subsequently, water is distributed through the pipeline network to serve residential and community demand. Within this system, the pipeline network plays a crucial role as the connection between the water source and end users. Therefore, the characteristics of the pipeline route directly influence distribution efficiency, pressure stability, and service continuity.

In addition to functioning as a temporary storage facility, the reservoir contributes to maintaining pressure stability and ensuring adequate water availability during periods of fluctuating demand. The presence of a reservoir enables the distribution system to continue operating effectively even when temporary disruptions occur within the network.

The schematic also demonstrates that the success of a water distribution system depends not only on the availability of water resources but also on the effectiveness of pipeline route planning. Appropriate route selection can reduce energy losses, maintain stable flow conditions, and improve the overall operational efficiency of the distribution network.

4. Discussion

Based on the results of the analysis, it can be observed that pipeline route selection has a significant influence on the performance of a clean water distribution system. Differences in route characteristics, particularly in terms of route length and elevation profile, directly affect energy losses and flow stability within the pipeline network. Therefore, route selection should not be based solely on the shortest distance but must also consider the terrain conditions through which the pipeline will be installed [9].

The findings indicate that Route A, which has the shortest alignment, is not necessarily the most favorable alternative. From a theoretical perspective, a shorter pipeline requires less construction material and may reduce initial capital costs. However, the considerable elevation differences along this route can increase the energy required to convey water through the system. As a consequence, pressure losses may occur at certain distribution points, potentially reducing the effectiveness and reliability of water delivery to consumers.

In contrast, Route B, which follows the natural terrain contours, demonstrates more stable hydraulic characteristics. Although this route requires a longer pipeline length, the relatively small elevation changes help reduce energy losses during water conveyance. This result highlights the importance of topographical considerations in pipeline system design. In regions with varied terrain conditions such as Kupang Regency, contour-following routes often provide better hydraulic performance than routes selected solely based on minimum distance.

Meanwhile, Route C, which combines elements of both previous alternatives, offers a compromise between technical efficiency and construction requirements. This route does not require a pipeline length as extensive as Route B, nor does it experience elevation changes as significant as Route A. Consequently, Route C may represent a practical alternative when financial limitations or site-specific constraints restrict the implementation of the technically optimal route. The performance of this route demonstrates that successful pipeline planning requires a balance among multiple design considerations rather than optimization of a single parameter.

Beyond hydraulic performance, pipeline route selection is closely related to economic considerations. The total length of the pipeline network influences material requirements, installation costs, and future maintenance expenditures. Longer routes generally require greater capital investment, while routes crossing difficult terrain may increase construction complexity and operational challenges. Therefore, route planning should seek an appropriate balance between technical performance and economic feasibility to ensure long-term sustainability [10].

The results also emphasize the importance of incorporating topographical analysis during the early stages of project planning. Inadequate route selection can increase energy losses and reduce the effectiveness of water distribution services. By utilizing elevation data and topographical mapping, planners can identify routes that offer improved hydraulic efficiency while minimizing operational risks and construction difficulties [11].

When viewed in relation to the objectives of this study, the findings confirm that route selection is one of the most critical factors determining the success of a clean water distribution system. The availability of a reliable water source, such as Raknamo Dam, will not provide maximum benefits unless supported by an efficiently designed distribution network. Consequently, evaluating multiple route alternatives is an essential step in ensuring that water can be delivered effectively and reliably to the communities that depend on it.

Furthermore, the findings suggest that route selection should be considered as part of an integrated water supply planning strategy rather than as an isolated engineering task. Effective route planning can improve service coverage, reduce operational inefficiencies, and enhance the resilience of the distribution system against future increases in water demand. This is particularly important in drought-prone regions where the reliability of water infrastructure plays a crucial role in supporting social and economic development [12], [13].

Overall, the results of this study are consistent with fundamental principles of pipeline network planning, which emphasize the need to balance topographical conditions, hydraulic efficiency, and economic considerations. By integrating these factors into the decision-making process, clean water distribution systems in Kupang Regency can be designed to provide more reliable services and contribute to mitigating the impacts of recurring drought conditions in the region [14], [15].

5. Conclusions

Based on the results of the analysis conducted in this study, it can be concluded that pipeline route selection plays a crucial role in determining the effectiveness of clean water distribution from Raknamo Dam to service areas in Kupang Regency. Each route alternative analyzed exhibits different characteristics in terms of route length, topographical conditions, and potential energy losses. These differences directly influence flow stability, distribution efficiency, and the overall performance of the water supply system.

The findings demonstrate that the shortest route does not always provide the most optimal solution. Although shorter routes may reduce material requirements and initial construction costs, significant elevation changes can increase head loss and negatively affect hydraulic performance. Conversely, routes that follow the natural contours of the terrain tend to provide more stable flow conditions and lower energy losses, despite requiring a longer pipeline length.

Among the alternatives evaluated, Route B offers the best hydraulic performance due to its relatively small elevation variations, while Route C provides a balanced solution between technical efficiency and construction feasibility. This indicates that route selection should be based on a comprehensive evaluation of multiple factors rather than a single parameter such as distance alone.

The study also highlights the importance of integrating topographical, hydraulic, and economic considerations during the planning stage of water distribution infrastructure. Careful route planning can improve service reliability, reduce operational costs, and enhance the long-term sustainability of the distribution network. Therefore, route optimization should be considered a fundamental component of water supply system design, particularly in regions characterized by challenging terrain and limited water availability.

Overall, the development of an effective pipeline network is essential for maximizing the benefits of Raknamo Dam as a primary water source. By selecting routes that balance hydraulic performance, construction practicality, and economic efficiency, clean water distribution systems can better support community needs and contribute to mitigating the impacts of drought in Kupang Regency. Future studies are recommended to incorporate detailed hydraulic modeling, Geographic Information System (GIS) analysis, and economic assessments to further improve route selection and infrastructure planning processes.

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