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Route Selection and Environmental Strategies in Subsea Pipeline Engineering

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Route Selection Analysis of Inter-Island Clean Water Pipeline to Address Water Crisis in Sumba Island

Abstract

The clean water crisis is one of the major challenges in dry island regions such as Pulau Sumba. Limited water resources, low rainfall, and uneven distribution have led to increasing demand for clean water. One proposed solution is the distribution of water from regions with better availability, such as Pulau Sumbawa, through a subsea pipeline system. This study aims to analyze the conceptual feasibility of inter-island clean water pipeline route selection by considering technical, environmental, and risk factors. The results indicate that route selection is a critical factor not only determined by distance but also by bathymetric conditions, seabed morphology, ocean currents, and geological risks. In addition, the project faces significant challenges in terms of cost and operation. Therefore, a comprehensive planning approach is required to ensure the technical feasibility and sustainability of inter-island clean water distribution systems.

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1. Introduction

Clean water availability is a fundamental requirement for sustaining human life and regional development. However, not all regions have adequate access to clean water resources, particularly in island areas characterized by dry climates. Sumba Island is drought prone area in Indonesia that most part of this island has about half a year of dryness without rainfall, included Central Sumba Regency [1]. Based on regional statistical data, the average annual rainfall is approximately 1000 mm, with a short rainy season lasting only about three months. The number of rainy days is limited to around 70 days per year, while the remaining nine months are dominated by the dry season. On the contrary, in December to March, wind blows from Asia and the Pacific Ocean and bringing lots of moisture and causes rainy season [1]. This situation changes every half year after the transition period in April-May and October-November. Instead of located closer to Australia, the wind that blows to Sumba Island from Asia and the Pacific Ocean looses much moisture and causes fewer rainy days in Central Sumba compared to regions closer to Asia [2].

As a result, water becomes a scarce resource. Low rainfall, limited surface water sources, and uneven water distribution cause significant difficulties for communities in meeting their daily water needs. This condition is further exacerbated by increasing demand due to population growth and tourism development. The clean water crisis directly affects public health, agricultural productivity, and regional economic conditions [3]. The population of Central Sumba Regency based on the 2024 population projection is 92,354 people consisting of 47,349 men and 45,005 women [1].

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One alternative solution is the distribution of clean water from regions with relatively better water availability, such as Sumbawa Island, through a subsea pipeline system. However, implementing an inter-island pipeline system is not a simple task. Unlike land-based distribution systems, subsea pipelines face various technical challenges, including bathymetric conditions, seabed morphology, ocean currents, and geological risks.

Inter-island subsea pipelines are among the most challenging infrastructure systems in marine engineering. The complexity arises from the need to install and operate pipelines under varying seabed conditions and environmental loads. As a result, careful planning is required to ensure long-term reliability and operational safety [4].

Another important consideration is the interaction between the pipeline and the marine environment. Factors such as seabed slope, sediment characteristics, and ocean currents can influence pipeline stability and increase the risk of structural damage. These conditions must be evaluated during the route selection process to reduce future operational problems [5].

In recent years, route selection has become a key component of subsea pipeline planning. Modern pipeline projects no longer focus solely on the shortest route but also consider technical feasibility, environmental constraints, and project risks. Therefore, a comprehensive route assessment is necessary to identify the most suitable alternative for inter-island water distribution.

Furthermore, route selection plays a key role in determining the success of the project, as the shortest path is not necessarily the safest or most economical. Therefore, this study aims to analyze the importance of route selection in planning inter-island clean water pipelines and to evaluate the technical and environmental challenges involved in the proposed water distribution from Sumbawa to Sumba.

2. Materials and Methods

This study employs a literature review and qualitative analysis approach. Data were collected from scientific sources such as journals, books, and reports related to subsea pipeline installation, oceanographic conditions, and water distribution systems.

The literature reviewed in this study includes publications related to marine engineering, subsea pipeline design, water resource management, and offshore infrastructure development. Relevant references were selected based on their applicability to inter-island water transfer systems and marine environmental conditions similar to those found between Sumbawa and Sumba.

The analysis focuses on identifying factors that influence the feasibility of subsea clean water pipeline installation. Particular attention is given to route selection, bathymetric conditions, seabed morphology, ocean currents, and geological hazards that may affect pipeline performance and long-term reliability.

The research steps include:

- Identification of water crisis issues in Sumba
- Assessment of water resource potential in Sumbawa
- Analysis of subsea pipeline route selection concepts
- Evaluation of marine conditions (bathymetry, currents, and sediment)
- Risk analysis and conceptual feasibility assessment

The approaches used in this study include:

- Route Selection Approach
- Hazard Identification
- Bathymetric and seabed morphology analysis

In addition, the collected information was synthesized to evaluate the relationship between route selection and project feasibility. The findings from previous studies were compared and interpreted to identify the main technical challenges and potential risks associated with inter-island clean water pipeline development.

This method is chosen to provide a conceptual understanding of project feasibility without requiring direct field data.

3. Results

The analysis shows that the clean water demand in Pulau Sumba is significantly high due to its semi-arid climatic conditions, characterized by low rainfall and prolonged dry seasons. According to Durriyyah et al. [6], regions in Southwest Sumba experience limited water availability due to low precipitation and high evapotranspiration rates, which reduce surface water retention. This condition leads to heavy reliance on seasonal water sources such as rainwater harvesting and shallow groundwater, which are often insufficient to meet daily needs. Furthermore, the uneven spatial distribution of water resources exacerbates accessibility issues, particularly in rural areas. Comparative regional studies indicate that areas within West Nusa Tenggara tend to have more favorable water availability compared to East Nusa Tenggara due to differences in climatic patterns [7]. This makes Sumbawa a potential candidate as a source region for inter-island water distribution.

However, the results also highlight that the implementation of a subsea pipeline between Sumbawa and Sumba faces significant technical challenges. These include variable bathymetry, steep seabed slopes, strong ocean currents, and potential geological hazards such as submarine landslides. According to Palmer and King [8], subsea pipeline installation in deep and uneven seabed conditions requires careful route optimization to minimize structural stress and ensure long-term stability. Therefore, route selection must consider not only the shortest distance but also seabed characteristics and environmental risks. The pipelines are exposed to extreme hydrostatic pressure and are primarily engineered to resist collapse [9].

3.1 Clean water Demand in Sumba Island

The analysis indicates that clean water demand in Sumba is significantly influenced by climatic, geographical, and socio-economic conditions. Limited rainfall and prolonged dry seasons reduce the availability of freshwater resources, while population growth and regional development continue to increase water consumption [10]. Based on the literature review, the main factors contributing to the high demand for clean water in Sumba can be classified as follows:

- Low rainfall and long dry seasons
- Limited surface water resources
- Uneven water distribution
- Increased demand from tourism development

3.2 Water Resource Potencial in Sumbawa Island

The results suggest that Sumbawa possesses relatively better water resource availability than Sumba. Favorable climatic conditions, supported by higher rainfall and the presence of natural water bodies, contribute to greater freshwater potential [11]. Based on the reviewed literature, the main factors supporting water resource availability in Sumbawa include:

- Higher rainfall
- Availability of rivers and reservoirs
- Favorable topographic conditions for water catchment

3.3 Subsea Pipeline Route Challenges

Route selection for an inter-island subsea pipeline involves various technical and environmental challenges that may affect project feasibility and long-term operation. Marine conditions between Sumbawa and Sumba are characterized by varying bathymetry, seabed morphology, and hydrodynamic processes that require careful assessment during the planning stage [12]. The key route-related challenges identified in this study are:

- Variable sea depth
- Seabed slope conditions
- Strong ocean currents
- Risks of earthquakes and submarine landslides

3.4 Risk Factor

The literature review indicates that subsea pipeline systems are exposed to a variety of operational and environmental risks throughout their service life. These risks may affect structural integrity, operational reliability, and maintenance requirements if not properly addressed during design and installation [13]. The major risk factors identified are:

- Damage due to ocean currents
- Sediment movement
- High pressure in deep waters
- Potential leakage

4. Discussion

The findings emphasize that route selection is a critical determinant in the feasibility of inter-island clean water pipeline projects. Traditional approaches that prioritize the shortest path are insufficient when applied to complex marine environments. Instead, a multi-criteria approach that incorporates bathymetric data, seabed morphology, and hazard assessment is required. Optimal pipeline routing must balance technical feasibility, environmental constraints, and economic considerations to reduce operational risks [14].

The importance of route selection becomes even more significant in long-distance inter-island pipeline projects. Unlike conventional onshore pipelines, subsea systems operate in environments where inspection, maintenance, and repair activities are considerably more difficult and costly. Consequently, route-related decisions made during the planning phase can have long-term implications for operational reliability and lifecycle costs. Selecting a route with favorable seabed conditions may reduce future maintenance requirements and improve overall system performance [15].

The marine area between Sumbawa and Sumba presents a highly dynamic environment influenced by strong ocean currents and tectonic activity. These conditions increase the likelihood of pipeline instability, including displacement and structural fatigue. Additionally, seabed sediment movement can lead to scouring, which exposes pipelines and increases the risk of failure. Research by Whitehouse [16] indicates that seabed erosion around pipelines is a major concern in offshore engineering and must be mitigated through appropriate design measures such as trenching or protective coatings.

In addition to physical environmental conditions, geological factors should also be considered during route evaluation. The waters surrounding eastern Indonesia are located within a tectonically active region characterized by frequent seismic activity. Although major subsea pipeline failures caused by earthquakes are relatively uncommon, tectonic movements may alter seabed conditions and increase the risk of localized instability. Therefore, geological hazard assessments should be incorporated into route selection and pipeline design processes [17].

From an economic perspective, the feasibility of inter-island water pipelines is significantly constrained by high capital and operational costs. Unlike oil and gas pipelines, which transport high-value commodities, water pipelines generate relatively low economic returns. According to Hidayah [3], the economic burden of water supply infrastructure is often a limiting factor in developing regions, making alternative solutions such as desalination or local water resource management more viable in certain contexts.

Despite these economic challenges, the social benefits associated with improved water availability should not be overlooked. Reliable access to clean water can contribute to better public health, increased agricultural productivity, and improved living standards. Furthermore, enhanced water security may support future economic development by reducing vulnerability to drought and water shortages. These broader benefits should be considered alongside financial costs when evaluating project feasibility [18].

Nevertheless, the urgency of addressing water scarcity in Sumba justifies the exploration of innovative solutions. An integrated approach that combines inter-island water transfer with local resource optimization may provide a more sustainable long-term strategy [19].

5. Conclusions

This study concludes that the development of a subsea pipeline for clean water distribution from Pulau Sumbawa to Pulau Sumba is technically feasible but involves substantial challenges. The high demand for water in Sumba is driven by climatic conditions, limited natural resources, and increasing socio-economic activities, as supported by previous studies [4].

The success of such a project largely depends on the accuracy of route selection, which must account for bathymetric variations, seabed conditions, and environmental risks. Failure to properly address these factors can lead to structural instability and increased maintenance costs [6]. Additionally, economic considerations remain a significant barrier, as the cost of construction and operation may outweigh the benefits when compared to alternative solutions.

Therefore, while inter-island pipeline systems present a potential solution to water scarcity, they should be evaluated within a broader framework that includes technical feasibility, economic sustainability, and environmental impact. A hybrid approach that integrates pipeline systems with local water management strategies is recommended to achieve long-term water security.

In addition, the study highlights that route selection should be regarded as a strategic planning component rather than merely a technical design activity. The selection of an appropriate route can significantly influence pipeline safety, operational reliability, maintenance requirements, and overall project sustainability. Therefore, future planning efforts should integrate oceanographic, geological, and environmental information to support more informed decision-making and reduce long-term operational risks.

Furthermore, this study is limited to a conceptual assessment based on literature review and qualitative analysis. Additional investigations involving detailed bathymetric surveys, hydrodynamic modeling, geotechnical assessments, and economic feasibility studies are required before project implementation can be considered. Such studies would provide a more comprehensive understanding of the technical and financial viability of inter-island clean water pipeline systems between Sumbawa and Sumba.

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