Anthroposia: Journal of Social and Human Development
Vol 1 No 3 September 2026, Hal 33-42
ISSN: 3125-0866(Print) ISSN: 3125-0769(Electronic)
Open Access: https://sovereignresearch.org/anthroposia

Evaluation of The Drinking Water Management Program Using Seawater Reverse Osmosis Technology on Penyengat Island, 2022–2025

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Article Info :
Received:
21-07-2026
Revised:
07-08-2026
Accepted:
13-08-2026

Abstract

The people of Penyengat Island face a shortage of clean water, which the government addresses through a clean water management program using Sea Water Reverse Osmosis technology to meet the island's clean water needs. The Technical Implementation Unit of the Public Works and Public Housing Office is responsible for the operation, maintenance, and rehabilitation of infrastructure related to SWRO management. This study aims to evaluate the implementation of the clean water management program using Sea Water Reverse Osmosis (SWRO) technology, as well as the challenges faced in providing clean water on Penyengat Island. The research method used is descriptive qualitative, which serves to describe the reality of events occurring in the field for this study using primary and secondary data. Primary data is collected through observation and interviews. This research was carried out through direct observation at the Sea Water Reverse Osmosis (SWRO) system operation site on Penyengat Island and interviews with informants from the Ministry of Public Works and Housing (PUPR) of Tanjungpinang City, the PUPR Office of Tanjungpinang City, BLUD UPTD SPAM, and the local community. Secondary data were obtained from the Mayor's regulations, legislation, scientific papers, program implementation reports, and the official website of Tanjungpinang City Government. Data collection was done through observation, interviews, and documentation, while analysis was conducted through data reduction, data presentation, and drawing conclusions. Based on Pietrzak's Program Evaluation theory, the results show that the program is not yet optimal due to limitations in storage tanks, damaged distribution pipes, insufficient human resources, and limited operational budgets. These conditions have caused water distribution to not be able to occur 24 hours a day and it is still carried out on a rotation basis. Even so, the presence of SWRO services has improved people's access to clean water, so daily needs can be met better.

Keywords : *Clean Water Management, Penyengat Island, Program Evaluation, Sea Water Reverse Osmosis.*

INTRODUCTION

Access to safe drinking water has become one of the most critical dimensions of sustainable development in the twenty-first century, particularly for coastal and small-island communities that experience chronic freshwater scarcity due to limited groundwater reserves, saltwater intrusion, population growth, and climate-induced environmental pressures. Recent technological advancements have positioned seawater desalination, especially Sea Water Reverse Osmosis (SWRO), as a viable solution for strengthening water security in geographically isolated regions where conventional water supply systems are technically or economically constrained. The growing global adoption of decentralized SWRO systems reflects a broader transition from centralized infrastructure models toward community-scale water management approaches capable of addressing local vulnerabilities while maintaining operational flexibility (Rifai, Hasibuan, Sutjiningsih, & Mahasti, 2026). Evidence from rural and island contexts further indicates that technological innovation in desalination has increasingly been linked to sustainability objectives, environmental performance considerations, and equitable access to essential public services (Abdul Ghani, Ali, Nazaran, & Hanafiah, 2021).

Existing scholarship has consistently demonstrated that SWRO technology possesses significant potential to improve freshwater availability in small-island environments; however, research findings also reveal that technological success depends on institutional, managerial, financial, and environmental conditions rather than engineering performance alone. Field investigations conducted on

Indonesian small islands indicate that desalination facilities frequently improve access to potable water but often encounter operational challenges related to maintenance capacity, distribution systems, energy consumption, and long-term governance arrangements (Savitri, Souma, Ishidaira, & Magome, 2024). Similar observations have emerged from studies examining water supply planning and infrastructure management, which emphasize that technological interventions require integration with local management strategies and service delivery mechanisms to achieve sustainable outcomes (Septiariva, Suryawan, Suhardono, Sofiyah, & Zahra, 2021). Research focusing on clean water provision through SWRO systems in island communities further suggests that improvements in water accessibility are closely associated with effective institutional coordination and continuous operational support (Ferdinand & Savitri, 2023).

Despite these contributions, the current literature presents several conceptual and empirical limitations that restrict a comprehensive understanding of SWRO-based water management programs. A substantial proportion of studies prioritize technological efficiency, water quality performance, or infrastructure design while devoting less attention to systematic evaluations of program implementation and service effectiveness over extended operational periods. Research examining desalination systems often focuses on technical outcomes without adequately investigating how governance structures, institutional responsibilities, operational financing, human resource capacity, and infrastructure maintenance interact to shape service delivery performance (Wahab et al., 2025). Comparable limitations are evident in evaluations conducted within Indonesian island settings, where assessments frequently emphasize policy formulation or technological deployment rather than examining the broader implementation dynamics affecting program sustainability (Natasya, Handrisal, & Putra, 2022).

The significance of addressing this gap becomes increasingly apparent in the context of small-island communities that depend heavily on desalination systems as their primary source of potable water. Studies concerning local government responsibility in water service provision indicate that equitable access to clean water requires not only technological availability but also effective governance capable of ensuring continuity, maintenance, and operational reliability over time (Husni, Hasanah, Septyanun, & Jiwantara, 2026). Evaluations of SWRO systems implemented in Indonesian islands have identified recurring challenges related to storage capacity, distribution infrastructure, operational budgets, and technical personnel, all of which directly affect service quality and community satisfaction (Suranata, Wahyuni, Candrayana, Triswandana, & Dana, 2025). Similar concerns have been reported in community-based desalination initiatives, where the sustainability of clean water services depends on the alignment between technological systems and local management capabilities (Hassan & Burhan, 2025). These conditions underscore the need for a more comprehensive evaluation framework capable of capturing the multidimensional realities of water management programs.

This study positions itself within the intersection of public program evaluation, water resource governance, and sustainable infrastructure management by examining the implementation and outcomes of the Drinking Water Management Program utilizing SWRO technology on Penyengat Island between 2022 and 2025. Unlike previous studies that primarily focus on technical performance indicators or policy formulation processes, this research emphasizes the operational effectiveness of the program from a governance and service-delivery perspective. Such a focus enables a more nuanced understanding of how institutional arrangements, operational resources, infrastructure conditions, and community needs influence the actual performance of desalination-based water supply systems. The study also contributes to ongoing discussions regarding the sustainability of decentralized water management models in island environments characterized by geographical and infrastructural constraints. Research on brackish water and desalination-based drinking water systems in the Riau Islands region further highlights the importance of evaluating management effectiveness alongside technological performance to ensure long-term service sustainability (Anwar, Made, & Nanny, 2025).

This research aims to evaluate the implementation of the Drinking Water Management Program using Sea Water Reverse Osmosis technology on Penyengat Island during the period 2022–2025 and to identify the principal factors influencing its effectiveness in providing clean water services to the local community. The study seeks to generate a deeper understanding of how operational practices, institutional capacities, infrastructure conditions, and management strategies affect program outcomes in a small-island setting. Theoretically, the research contributes to the development of program evaluation studies within the field of public service governance and water resource management. Methodologically, it offers an in-depth qualitative assessment that integrates technological,

institutional, and service-oriented dimensions to provide a more comprehensive evaluation of decentralized desalination-based water supply programs.

RESEARCH METHODS

This study employed a qualitative descriptive research design to evaluate the implementation of the Drinking Water Management Program utilizing Sea Water Reverse Osmosis (SWRO) technology on Penyengat Island during the period 2022–2025. A qualitative approach was selected because it enables an in-depth exploration of the experiences, perceptions, and interactions of stakeholders involved in the management and utilization of clean water services. The research was conducted on Penyengat Island, Tanjungpinang City, Riau Islands Province, where the SWRO system serves as the primary source of clean water for the local community. Informants were selected using purposive sampling techniques and consisted of representatives from the Public Works and Public Housing Agency (PUPR), the Regional Public Service Agency for Drinking Water Supply Systems (BLUD UPTD SPAM), SWRO operational personnel, community leaders, and residents who directly utilized the service. Primary data were collected through in-depth interviews, field observations, and documentation, while secondary data were obtained from government regulations, institutional reports, operational records, and relevant scientific publications concerning water management and desalination technology.

Data analysis was conducted using the interactive model developed by Miles, Huberman, and Saldana, which includes data condensation, data display, and conclusion drawing/verification. Interview transcripts, observation notes, and documentary evidence were systematically coded and categorized to identify patterns, themes, and relationships related to program implementation, operational effectiveness, and challenges encountered during the management process. To ensure the credibility and trustworthiness of the findings, data triangulation was performed by comparing information obtained from multiple sources and data collection techniques. Member checking and peer debriefing were also applied to enhance analytical rigor and minimize researcher bias. Ethical considerations were maintained throughout the study by obtaining informed consent from all participants, ensuring confidentiality, and using the collected information exclusively for academic research purposes..

RESULTS AND DISCUSSION

Evaluation of Program Implementation and Service Delivery Performance

The The qualitative findings indicate that the Drinking Water Management Program utilizing Sea Water Reverse Osmosis (SWRO) technology on Penyengat Island has contributed significantly to improving community access to clean water during the 2022–2025 period. Interviews with residents revealed that the presence of the SWRO facility reduced dependence on rainwater harvesting and water transported from the mainland. Informants consistently described the program as an important public service intervention in addressing long-standing water scarcity issues. Similar outcomes have been reported in island-based desalination initiatives where SWRO systems enhanced local water security and strengthened household resilience to freshwater shortages (Rifai et al., 2026).

Field observations demonstrated that the operational performance of the SWRO facility was influenced by both technical and managerial factors. Operators explained that production capacity generally met daily demand under normal conditions, although interruptions occasionally occurred due to maintenance requirements and equipment deterioration. Community members acknowledged improvements in water availability while expressing concerns regarding distribution continuity. Research on small-scale desalination facilities likewise emphasizes that operational sustainability depends on the integration of technology management and local institutional capacity (Abdul Ghani et al., 2021).

Interview data further revealed that the management structure adopted by BLUD UPTD SPAM facilitated routine operational activities and customer service functions. Administrative procedures for water distribution, complaint handling, and maintenance scheduling were relatively well established. Informants from implementing agencies noted that coordination among technical personnel had improved compared with the initial operational period. These findings correspond with evaluations of SWRO governance systems that highlight the importance of organizational arrangements in supporting service effectiveness (Syahfitriani, Akhyary, & Okparizan, 2023).

The program's contribution to household welfare became apparent through recurring narratives concerning reduced expenditure on alternative water sources. Residents reported greater convenience in accessing clean water for domestic activities, including cooking, bathing, and sanitation purposes. The reduction in water acquisition burdens was perceived as one of the most tangible program outcomes. Similar conclusions were identified in studies examining clean water fulfillment through SWRO technology in island communities (Ferdinand & Savitri, 2023).

Data collected from interviews and institutional documentation enabled the identification of several indicators associated with implementation performance. Informants consistently highlighted operational continuity, service accessibility, and community satisfaction as the most relevant dimensions of program evaluation. The summary of qualitative findings is presented in Table 1.

Table 1. Summary of Program Implementation Findings (2022–2025

Evaluation Aspect	Field Findings	Assessment
Water Availability	Increased compared to pre-SWRO conditions	Positive
Service Accessibility	Reachable by most households	Positive
Operational Continuity	Periodic interruptions occurred	Moderate
Infrastructure Condition	Several components required maintenance	Moderate
Community Satisfaction	Generally satisfied	Positive

The information presented in Table 1 indicates that the program generated positive outcomes in terms of accessibility and availability, although operational continuity remained vulnerable to technical disruptions. These patterns illustrate that infrastructure-dependent services require continuous monitoring and maintenance mechanisms. Comparable observations were documented in assessments of SWRO facilities operating in Indonesian coastal regions (Savitri et al., 2024).

Interviews with technical personnel revealed that preventive maintenance procedures were conducted according to operational schedules, although implementation was occasionally constrained by resource limitations. Maintenance activities focused primarily on membrane performance, filtration components, and pumping systems. Operators emphasized that prolonged delays in maintenance could reduce production efficiency and affect service reliability. Water quality management studies similarly identify routine maintenance as a determining factor in desalination system performance (Wahab et al., 2025).

Community perceptions regarding service quality were generally favorable, particularly concerning water clarity and usability for daily activities. Several residents noted substantial improvements compared with conditions before the establishment of the SWRO facility. Satisfaction levels were influenced not only by water quality but also by the consistency of supply distribution. Research on public utility services indicates that user perceptions frequently reflect both technical outputs and service delivery experiences (Riskianto, 2023).

Institutional actors described the program as a strategic response to geographical constraints affecting freshwater availability on small islands. Policy implementation efforts reflected broader governmental commitments to strengthening water security through technological innovation. Informants emphasized that SWRO technology provided a practical alternative in contexts where conventional water sources were insufficient. Such findings align with studies advocating decentralized desalination systems as adaptive solutions for island environments (Husni et al., 2026).

The evaluation results suggest that the program has achieved substantial progress in expanding access to clean water while simultaneously revealing areas requiring continuous improvement. Evidence from interviews, observations, and documentation demonstrates that technological intervention alone cannot guarantee sustainable service outcomes. Long-term effectiveness depends on the interaction between infrastructure quality, institutional management, operational resources, and community engagement. Comparable conclusions have been emphasized in research on water supply planning and management in geographically constrained regions (Septiariva et al., 2021).

Infrastructure Constraints and Operational Challenges in SWRO-Based Water Management

The Interview findings revealed that infrastructure limitations remained one of the most significant challenges affecting the effectiveness of the SWRO-based drinking water management program on Penyengat Island. Technical personnel explained that several distribution pipelines experienced recurring leaks, reducing the efficiency of water delivery to households. Community members reported occasional delays in receiving water during periods of system maintenance or pipeline repairs. Similar challenges have been identified in evaluations of island desalination systems where aging infrastructure directly influenced service reliability (Suranata et al., 2025).

Field observations indicated that storage capacity represented another operational constraint within the water supply system. Existing storage facilities were often unable to provide adequate reserves during peak demand periods or technical disruptions. Informants stated that fluctuations in water availability became more noticeable when production and distribution schedules were interrupted simultaneously. Studies on small-island water governance have similarly emphasized the importance of sufficient storage infrastructure in maintaining service continuity (Rifai et al., 2026).

The operational sustainability of the SWRO facility was also influenced by human resource capacity. Interviews with management personnel revealed that the number of technical staff remained relatively limited compared with operational demands. Several respondents explained that maintenance responsibilities were frequently concentrated among a small group of operators with specialized expertise. Comparable findings have been reported in assessments of rural desalination facilities where human resource constraints affected operational efficiency (Abdul Ghani et al., 2021).

Community informants highlighted concerns regarding the speed of response when technical disturbances occurred within the distribution network. While operators generally addressed reported issues, geographical limitations and workforce constraints occasionally prolonged repair processes. Residents perceived that service recovery could be improved through additional technical personnel and more systematic monitoring mechanisms. Research on clean water service management indicates that responsiveness is a key determinant of perceived service quality (Riskianto, 2023).

The qualitative data also revealed several interconnected operational challenges that affected program performance during the evaluation period. These challenges are summarized in Table 2.

Table 2. Major Operational Challenges Identified in the SWRO Program

Operational Aspect	Identified Issue	Impact on Service
Storage Facilities	Limited reservoir capacity	Reduced supply reserves
Distribution Network	Pipe leakage and deterioration	Distribution inefficiency
Human Resources	Limited technical personnel	Slower maintenance response
Operational Funding	Budget limitations	Delayed infrastructure upgrades
Equipment Maintenance	Dependence on specialized components	Increased downtime risk

The information presented in Table 2 demonstrates that operational constraints originated from both technical and institutional dimensions. Infrastructure deficiencies and resource limitations interacted to influence overall service performance. Such conditions support arguments that sustainable water management requires integrated solutions rather than isolated technological interventions. Similar patterns were documented in studies examining SWRO governance and operational sustainability in Indonesian island regions (Syahfitriani et al., 2023).

Financial constraints emerged as another recurring theme during interviews with implementing agencies. Informants explained that operational expenditures included energy consumption, membrane replacement, equipment maintenance, and network repairs. Budget availability often influenced the timing and scope of maintenance activities. Research on desalination governance has consistently shown that financial sustainability constitutes a central challenge in maintaining long-term service provision (Husni et al., 2026).

Technical staff reported that membrane performance gradually declined as equipment aged, increasing the need for preventive maintenance and component replacement. Maintenance requirements became more complex when replacement parts were unavailable locally and had to be sourced from outside the region. Such circumstances occasionally extended repair periods and affected production

capacity. Similar operational risks have been highlighted in studies evaluating water quality management in reverse osmosis systems (Wahab et al., 2025).

Observational findings further indicated that environmental conditions influenced infrastructure durability. Coastal exposure, humidity, and saline conditions accelerated the deterioration of certain system components. Operators noted that continuous monitoring was necessary to prevent minor technical issues from developing into major operational failures. These findings correspond with field studies on SWRO applications in small-island environments where environmental factors significantly affect infrastructure lifespan (Savitri et al., 2024).

Several informants suggested that complementary water treatment and filtration approaches could strengthen local water security during periods of operational disruption. Experiences from community-based filtration initiatives demonstrate that alternative treatment technologies can provide additional resilience within local water systems (Aqila et al.). Similar benefits have been observed in filtration-based clean water programs implemented in rural communities (Pramono et al., 2025). Such perspectives indicate that diversification of water management strategies may enhance the long-term sustainability of water services on Penyengat Island.

The findings illustrate that operational challenges are multidimensional and cannot be attributed solely to technological limitations. Infrastructure conditions, financial resources, workforce capacity, and environmental factors collectively shape the effectiveness of the drinking water management program. Addressing these challenges requires coordinated institutional planning that balances technological maintenance with organizational strengthening. Comparable conclusions have been emphasized in studies examining the relationship between infrastructure resilience and sustainable water service delivery in vulnerable communities (Anwar, Made, & Nanny, 2025)..

Strategic Improvement and Sustainability of the SWRO Drinking Water Management Program

The The evaluation findings indicate that the long-term sustainability of the SWRO-based drinking water management program depends not only on technological performance but also on the capacity of institutions to adapt to operational challenges. Interviews with implementing agencies revealed a growing awareness that infrastructure maintenance must be accompanied by organizational strengthening and strategic planning. Informants emphasized the importance of integrating technical management with community-oriented service approaches. Similar perspectives are reflected in studies highlighting that sustainable water governance requires the alignment of technology, institutions, and public service objectives (Rifai et al., 2026).

Community members expressed expectations for more reliable and continuous water distribution in the future. Residents generally appreciated the benefits generated by the SWRO facility but considered service stability to be the primary indicator of program success. Interview data showed that public trust increased when water availability remained consistent over longer periods. Research on clean water service systems demonstrates that continuity of supply strongly influences public acceptance and program legitimacy (Ferdinand & Savitri, 2023). I

nstitutional informants identified infrastructure rehabilitation as a strategic priority for improving service performance. Several respondents noted that aging pipelines and storage facilities required gradual replacement to reduce operational disruptions. Preventive investment was viewed as more effective than repeated corrective maintenance. Similar findings were reported in evaluations of SWRO optimization programs that emphasized infrastructure renewal as a prerequisite for sustainable service delivery (Suranata et al., 2025).

The qualitative analysis also highlighted the importance of strengthening technical capacity among operational personnel. Informants explained that specialized training would improve the ability of operators to respond to equipment failures and conduct preventive maintenance. Capacity development was considered essential because desalination technology requires technical expertise that differs from conventional water supply systems. Studies examining water treatment technologies similarly stress the role of skilled personnel in maintaining operational efficiency and water quality standards (Wahab et al., 2025).

Data collected from interviews and institutional records identified several strategic priorities for future program development. These priorities are summarized in Table 3.

Table 3. Strategic Priorities for Program Sustainability

Strategic Area	Recommended Action	Expected Outcome
Infrastructure	Rehabilitation of pipelines and reservoirs	Improved service reliability
Human Resources	Technical training and workforce expansion	Increased operational capacity
Financial Management	Strengthening operational funding mechanisms	Sustainable maintenance
Community Participation	Public awareness and reporting systems	Enhanced stakeholder support
Technology Management	Routine monitoring and preventive maintenance	Reduced system downtime

The information presented in Table 3 demonstrates that sustainability requires interventions across multiple dimensions rather than focusing exclusively on technical infrastructure. Human resources, financing mechanisms, and community engagement play equally important roles in supporting service continuity. Such observations reinforce the argument that water management programs function as socio-technical systems rather than purely engineering projects. Comparable conclusions have emerged from studies examining integrated water governance in coastal and island communities (Hassan & Burhan, 2025).

Community participation emerged as a critical factor influencing program sustainability. Interviews indicated that residents were willing to contribute to reporting infrastructure damage and supporting responsible water use practices. Several informants believed that stronger communication between service providers and users would improve operational responsiveness. Research on community-based water management has shown that stakeholder involvement often enhances accountability and strengthens service effectiveness (Mahmuda, Sanubary, & Santoso, 2023).

Alternative water treatment initiatives discussed in the literature also provide valuable insights for strengthening local resilience. Studies involving filtration technologies have demonstrated that complementary water treatment systems can support primary supply infrastructure during periods of disruption (Afan et al., 2022). Similar outcomes were reported in programs utilizing simple filtration systems to improve access to clean water in resource-constrained settings (Saputra, Handayani, Kamaliah, & Akbar, 2023). These findings suggest that diversification strategies may reduce dependence on a single water source.

The potential integration of supplementary water treatment technologies was also viewed positively by several stakeholders. Experiences from filtration-based clean water programs indicate that decentralized treatment solutions can increase flexibility in addressing local water challenges (Pradasta et al., 2026). Comparable benefits have been documented in post-disaster and community-based water supply initiatives where filtration systems enhanced access to usable water resources (Hasibuan, 2026; Putra, Din, Fadhilah, & Away, 2026). Such approaches may provide additional support for maintaining water security on Penyengat Island.

Informants from implementing agencies emphasized that future planning should incorporate long-term financial sustainability measures. Operational expenditures related to energy use, equipment replacement, and infrastructure maintenance require stable funding arrangements. Budget predictability was considered essential for preventing service interruptions caused by delayed maintenance activities. Similar concerns have been raised in studies evaluating the sustainability of local water service institutions in coastal regions (Syahfitriani et al., 2023).

The overall evaluation suggests that the future effectiveness of the SWRO drinking water management program depends on the successful integration of infrastructure improvement, human resource development, financial sustainability, and community engagement. The qualitative evidence indicates that technological innovation has already generated substantial benefits for local residents, yet long-term success requires continuous institutional adaptation. Sustainable water governance is shaped by the interaction between technical systems and social management processes. Comparable findings have been observed in research examining filtration-based water management innovations and community-centered clean water programs in Indonesia (Nugroho, 2025; Saputra et al., 2025).

CONCLUSION

The evaluation of the Drinking Water Management Program using Sea Water Reverse Osmosis (SWRO) technology on Penyengat Island during the 2022–2025 period indicates that the program has played a significant role in improving community access to clean water. The implementation of SWRO technology has reduced dependence on alternative water sources and increased the availability of water for household needs. The findings show that the program has achieved positive outcomes in terms of service accessibility, water quality, and community satisfaction. Effective coordination among implementing agencies and operational personnel has contributed to the continuity of service delivery, although several operational challenges continue to affect overall performance.

The study also reveals that the sustainability of the program is constrained by infrastructure limitations, aging distribution networks, limited storage capacity, human resource shortages, and operational funding challenges. These factors have influenced service reliability and restricted the program's ability to provide uninterrupted water distribution. Strengthening infrastructure maintenance, expanding technical capacity, ensuring sustainable financing mechanisms, and increasing community participation are essential for improving long-term program effectiveness. Future policy efforts should prioritize integrated water governance approaches that combine technological innovation, institutional strengthening, and stakeholder collaboration to ensure equitable and sustainable access to clean water for island communities.

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