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Analytic Network Process (ANP) and Benefit Cost Opportunity Risk (BCOR) Approach for Selecting Sustainable Water Quality Management Strategies

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Abstract. Water resource management faces complex challenges in decision-making, particularly in selecting effective strategies to restore polluted river water quality. Kali Surabaya, as a strategic water source, has experienced quality deterioration due to domestic and industrial pollution, compounded by climate change pressures. Recent assessments indicate mild pollution with several parameters not meeting quality standards. Given resource constraints and rising demands for class I and II raw water, a systematic approach is necessary to determine the optimal recovery strategies. This study employs the Analytic Network Process (ANP) method integrated with the Benefit, Cost, Opportunity, and Risk (BCOR) framework to evaluate interrelated criteria and sub-criteria, identifying strategic priorities specifically in the Kali Tengah segment, which faces considerable pollution pressure. Based on literature review, water quality data, and expert questionnaire results, the primary criteria identified for strategy selection show Benefit (0.4127) as the highest priority, followed by Opportunity (0.23118), Cost (0.1292), and Risk (0.0695). The recommended strategies with optimistic scenario values include establishing communal industrial wastewater treatment (10.8102), applying nanobubble technology (0.6534), and periodic flushing (0.1396). Considering sustainability aspects (economic, social & environmental), this integrated approach aims to enhance long-term water quality management efforts.
Keywords: service quality, member satisfaction, KSPPS, BMT, sharia cooperative

INTRODUCTION

Water resource management is one of the strategic challenges amid the increasing demand for clean water, both for domestic, industrial, and agricultural purposes (Ishaque et al., 2023; Keyhanpour et al., 2021; Kodoatie & Sjarief, 2005; Shams & Muhammad, 2022; Zhang & Oki, 2023). Conversely, water quality in various regions of Indonesia continues to decline due to domestic and industrial waste pollution, as well as pressures from climate change. One notable case is the *Surabaya River*, which serves as a primary raw water source for the Surabaya area and its surroundings. Currently, it functions not only as a water supply for households but also fulfills the needs of industry, irrigation, and drinking water services provided by *PDAM*; thus, both the quality and quantity of water are critically important.

Alongside rising demand for quality raw water, water resource management institutions face two main challenges: resource constraints—including budgetary, technological, and institutional capacity limitations—and the complexity of selecting the most appropriate and sustainable water quality restoration strategy. Management strategies cannot rely solely on technical solutions but must incorporate social, economic, and environmental dimensions holistically. Such complexity necessitates decision-making that integrates multiple criteria with interdependencies and mutual influences among each aspect.

The *Surabaya River*, a tributary of the *Brantas River* extending approximately 41 km from the *Mlirip Water Gate* to the Java Sea, plays a vital role in meeting local water needs. However, in recent years, it has encountered numerous challenges, including pollution from domestic and industrial waste, drought during dry seasons, and increasing demand pressures from industry and *PDAM*. Climate change exacerbates this situation through extreme weather patterns: heavy rains cause flooding, and prolonged dry periods lead to severe droughts, both directly impacting water supply continuity (Eccles et al., 2019).

Declining water quality in the *Surabaya River* has raised concerns among stakeholders. Studies report increasing pollutant levels such as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), and heavy metals, rendering the river unsuitable as a raw water source without intensive treatment. Conventional technologies are insufficient to address high pollution levels effectively, calling for more efficient and innovative approaches (Laili, 2021; Miko et al., 2019; Said et al., 2020; Yudo & Said, 2019b, 2019a). Research by Suwari et al. (2010) further emphasizes the importance of monitoring critical parameters, such as Dissolved Oxygen (DO) and BOD, which significantly influence the river's natural purification capacity. Simulation studies warn of escalating heavy metal concentrations in the long term without adequate intervention (Bockholt et al., 2022; Lakshmikantha et al., 2021; Lindholm-Lehto, 2023; Lowe et al., 2022).

Beyond technical factors, pollution problems in the *Surabaya River* are worsened by weak enforcement of land management regulations and insufficient supervision of waste disposal. Consequently, water quality degradation becomes increasingly difficult to control, adversely affecting communities and industries dependent on the river's water supply. This situation underscores the necessity of comprehensive, collaborative management. Stakeholder collaboration—including stringent law enforcement, community education, river conservation, and optimizing the role of water resources management companies—is fundamental.

In this context, water quality restoration cannot be addressed sectorally but requires a systemic, data-driven approach. One promising method is the integration of the Analytic Network Process (ANP) with the Benefit-Cost-Opportunity-Risk (BCOR) model. ANP facilitates simultaneous analysis of interrelated criteria, while BCOR provides a robust framework for evaluating strategies based on their benefits, costs, opportunities, and risks. Together, this integrated approach accommodates systemic complexity and supports more rational, targeted decision-making (Ciptomulyono, 2024; Saaty & Vargas, 2006).

Water Resources Management Companies have a pivotal role in implementing restoration strategies. Leveraging their technical and institutional capacities, these companies can initiate technology- and policy-based solutions, including strengthening water quality monitoring systems, adopting nanobubble technology, constructing communal wastewater treatment plants (WWTP), and developing pollutant disposal strategies to reduce contaminant concentrations. The success of these strategies depends heavily on cross-sectoral synchronization and regulatory backing. Enhanced collaboration among local governments, academia, industries, and civil society is essential to ensure sustainable water quality restoration efforts.

Considering the complexities outlined above, this study formulates the primary research question: how to select an optimal and feasible water quality management strategy for Water Resources Management Companies to address pollution in the *Surabaya River*. The study objectives are to: (1) evaluate existing water quality management strategies; (2) identify key criteria influencing decision-making; (3) apply a multi-criteria analysis using the ANP and BCOR methods; and (4) recommend the most optimal priority strategies to support the availability of quality raw water. The research aims to provide a scientific basis for decision-making, promote sustainable water resource management, and strengthen the strategic role of management companies in adaptive and sustainable water quality governance.

Urban water resource management has become a critical issue due to rising demand and deteriorating water quality. Previous studies Yudo & Said (2019b) document severe pollution in the *Surabaya River*, characterized by elevated BOD, COD, and heavy metal concentrations. These studies highlight the limitations of conventional treatment and call for innovative solutions. Additionally, Suwari et al. (2010) identified dissolved oxygen (DO) as a critical parameter for the river's selfpurification capacity. However, these studies often focus on technical perspectives without integrating multi-criteria decision-making frameworks that holistically evaluate sustainable management strategies, leaving a gap in policy and operational guidance.

The existing research gap lies in the absence of a systemic approach that incorporates technical, social, economic, and environmental dimensions within water quality management. Most studies address pollution control in isolation, overlooking the interconnectedness among cost, risk, and stakeholder collaboration. For example, while nanobubble technology and communal WWTPs have been investigated individually, their comparative effectiveness and feasibility in the unique context of the *Surabaya River* are underexplored. Moreover, advanced decision-making tools such as ANP and BCOR remain largely unutilized in this region, despite their potential to offer structured, data-driven strategy selection.

The urgency of this research is propelled by the worsening pollution crisis in the *Surabaya River*, threatening water supplies for domestic, industrial, and agricultural sectors. Climate change intensifies this issue through extreme weather events that disrupt water availability and quality. The river's deteriorating condition, evidenced by recurring pollutant spikes, demands immediate and sustainable interventions. Without effective strategies, aquatic ecosystems and dependent communities face escalating risks. This study addresses this urgency by proposing actionable, multi-criteria-based solutions that are both practical and aligned with local water management capacities.

This research contributes novelty by integrating ANP and BCOR methodologies to evaluate water quality management strategies—an approach seldom applied to Indonesian rivers. By combining expert judgment and quantitative data, the study delivers a balanced assessment of alternatives such as nanobubble technology, communal WWTP, and pollutant dumping strategies, measuring their benefits, costs, opportunities, and risks. The inclusion of sensitivity analysis enhances robustness, ensuring selected strategies remain viable under varying scenarios. This methodological innovation offers a replicable framework for other regions confronting similar water quality challenges, bridging the gap between theoretical models and practical application.

The study's objectives are to identify optimal water quality management strategies for the *Surabaya River*, assess their feasibility using ANP and BCOR, and provide evidence-based recommendations for policymakers and water management entities. It aims to improve decision-making by prioritizing strategies that balance technical efficacy, economic viability, and environmental sustainability. Expected benefits include enhanced raw water quality, strengthened institutional capacity, and a model for collaborative governance among stakeholders. By addressing identified research gaps and urgent challenges with a novel methodology, this study advances sustainable water resource management and offers scalable solutions for polluted urban rivers worldwide.

MATERIALS AND METHODS

Based on observations and expert interviews with the Water Resources Management Company, the formulation of alternative strategies for restoring water quality in the *Surabaya River* takes into account limitations in authority, technical capacity, and resources available to the company. The proposed strategies are designed to be both realistic and operational within the company's internal capabilities, while also aligning with the company's institutional mandate and responsibility to support sustainable water quality management efforts. The three prioritized alternative strategies in this study include: (1) *dumping* as a technical measure to reduce waste concentrations; (2) the construction of communal Wastewater Treatment Plants (WWTP) for industry as a collective pollution reduction approach; and (3) the application of nanobubble technology as an innovative solution to increase dissolved oxygen (DO) levels and reduce pollutant loads in water bodies.

This study employs a combination of primary and secondary data to support strategic analysis in water quality management. The methodological approach integrates the Analytic Network Process (ANP) with the Benefit-Cost-Opportunity-Risk (BCOR) model. Primary data were collected through questionnaires distributed to experts drawn from diverse stakeholder backgrounds, including academia, government agencies, and water resources management companies. Respondent selection was purposive, based on qualifications such as a minimum of five years' experience in water resource management, at least one level of formal education, comprehensive knowledge of water quality management policies and technical practices, and direct involvement in research or activities related to the *Surabaya River*.

In this study, the sample comprised three respondents: one representative from the East Java Provincial Environmental Agency, one academic affiliated with a university specializing in environmental research, and one Level II structural official from the Natural Resources Management Company. These criteria ensure that the data reflect relevant professional expertise and experience, grounded in strong technical and policy knowledge. Moreover, the direct engagement of these experts with water quality management issues in the *Surabaya River* enhances the validity and relevance of the strategic analysis outcomes.

Secondary data were obtained through literature reviews, company reports, and official government documents related to water resource management. These data included water quality parameters such as DO, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), hydrological statistics, and applicable environmental regulations. The secondary data were used to assess the current condition of the *Surabaya River*, evaluate the effectiveness of previously implemented strategies, and provide a basis for decision-making modeling.

All collected data were processed using Super Decisions software to apply the ANP methodology in evaluating and selecting the optimal strategy. The selection process incorporated BCOR analysis, which considers the benefits, costs, opportunities, and risks associated with each proposed alternative strategy.

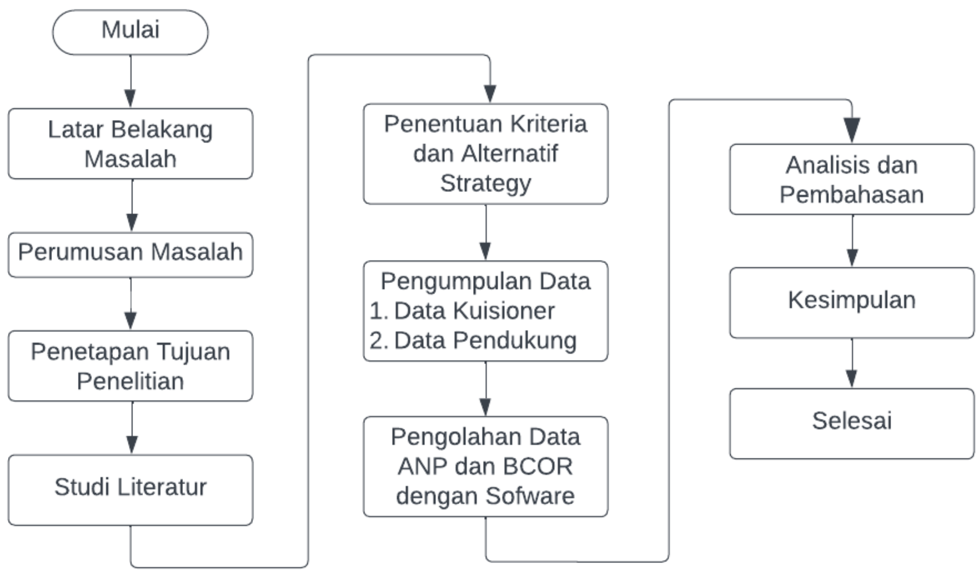

Figure 1. Research Flow Diagram

RESULTS AND DISCUSSION

River Management

Integrated management of water resources is essential to ensure sustainable water availability.

This approach not only considers the needs in various sectors but also considers the balance between future demand and current availability, while maintaining sustainability on social, economic, and environmental aspects.

In recent decades, many countries in Asia have begun to implement national policies in river area-based water management. Although still in its infancy, this approach has provided a clearer direction in water resource management. River management organizations play an important role in facilitating and implementing various water development and management efforts.

In various Asia Pacific countries, river management is carried out by various parties, both on a small and large scale, which helps governments and stakeholders realize better management of water resources. Some are managed directly by the government, but some are in the form of companies or semi-companies to be more flexible and independent in financial management, development, and management.

The management of river areas is adjusted to local characteristics, including natural conditions, water utilization needs, and various existing interests. Therefore, river basin management organizations or River Basin Organization (RBO) can operate in various forms, such as councils, committees, authorities, commissions, agencies, corporations, water boards, and others.

The organizational structure of the RBO is formed based on management needs and its roles and responsibilities in managing river areas. As shown in Table 1, each form of organization has different functions, ranging from regulations, development planning, project implementation, system operation, to cross-sector coordination. Thus, the selection of the right organizational form will support the effectiveness of river area management.

Water Resources Management Company

Perum Jasa Tirta I (PJT I) is a State-Owned Enterprise (BUMN) that is responsible for the management of water resources in accordance with Government Regulation (PP) No. 46 of 2010. The main task of PJT I is based on the five pillars of water resources management, namely natural resource conservation, water damage control, natural resource utilization, community empowerment, and natural resource information systems. The natural resource conservation pillar includes efforts to preserve and protect water catchment areas so that they continue to function optimally. The control of water damage, especially floods, is the second priority in the management of natural resources by PJT I consider its impact on settlements, infrastructure, and the economic sector. Natural resource utilization is carried out through the sustainable use of water for various needs, including raw water, irrigation, and energy. Community empowerment aims to increase community participation in natural resource management, while natural resource information systems serve as the basis for data-based decision-making related to water resource conditions. Currently, PJT I manage five main river areas, namely the Brantas River Area (WS), WS Bengawan Solo, WS Jratun Seluna, WS Serayu Bogowonto, and WS Toba Asahan, with an approach that balances aspects of water resource utilization and conservation.

The Brantas River Area (WS) is one of the PJT1 work areas located in East Java Province, the Brantas River headwaters at the foot of Mount Arjuno, precisely Sumber Brantas Village, Bumiaji District, Batu City. This river then flows into Malang City and then meets the Lesti River in Malang Regency. This river then flows into Blitar and meets the Ngrowo River in Tulungagung. This river then flows into Kediri and meets the Widas River in Kertosono. This river then flows into Jombang and branches into two in Mojokerto, namely the Surabaya River and the Porong River. With a watershed area (DAS) Brantas reaches 11,800 km^2 or a quarter of the area of East Java Province. The 320-kilometer Brantas River flows around a volcano that is still active, Mount Kelud. The average rainfall in this river area reaches 2,000 mm per year and of this amount, about 85% of it falls in the rainy season.

The average potential of surface water in this river area is 12 billion m³ per year, and the new utilization is 2.6-3.0 billion m³ per year.

PJT I manage various main infrastructures such as the Sengguruh, Sutami, Selorejo and Wlingi Dams to support the supply of raw water, irrigation, and hydropower plants. Along with population and industry growth in downstream areas, the need for raw water is increasing, especially for the household, industrial, and agricultural sectors. On the other hand, flood control is a big challenge, especially in downstream areas that often experience inundation during the rainy season due to sedimentation and land use changes. In terms of water quality management carried out by PJT I, it is still limited to regular water quality monitoring to find out the current condition of the rivers in its working area. The results of this monitoring are then submitted to relevant stakeholders such as local governments and environmental supervisory agencies that have the authority to take action against pollution or deviations from the water quality standards that have been set.

Water Quality Conditions in the Surabaya River

PJT I periodically monitor water quality in the Brantas River Area in 57 (fifty-seven) locations on water sources (rivers and reservoirs), as well as in 58 (fifty-eight) waste disposal locations (industrial, domestic, hotel and hospital).

For the Surabaya River area, sampling was carried out at 6 (six) sampling point locations ranging from Perning Bridge, Jebreng Bridge, Cup Mine, Bamboo Mine, Karangpilang, Sepanjang Bridge, Bd Gunungsari and Jagir Ngagel PA.

Especially in the Surabaya River, which is part of the downstream of the Brantas River, there are currently fluctuations in pollution load, especially from the Central River. Until now, there is no best solution to the pollution problem, so further efforts are needed from various parties to effectively deal with the source of pollution. Through the implementation of the five pillars of natural resources, PJT I continue to contribute to maintaining the sustainability of WS Brantas and other river areas as a source of life for the community and the economic sector.

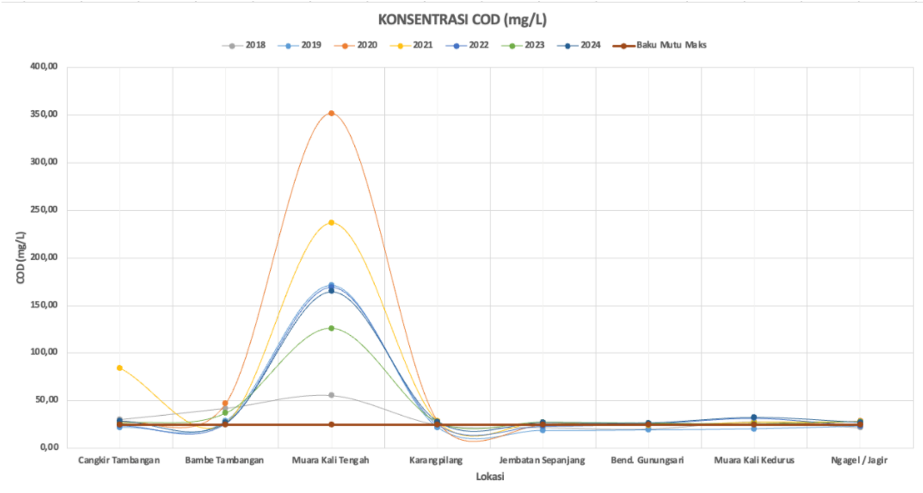

Figure 1. Graph of COD Parameter Water Quality Test Results from 2018 – 2024 (PJT1,2024)

The graph above shows the change in COD (Chemical Oxygen Demand) concentration in the Surabay River from 2018 to 2024. From the available data, it can be seen that there has been a drastic spike in Muara Kali Tengah, especially in 2020 and 2021, with the highest peak in 2020 exceeding 350 mg/L. After this period, COD concentration gradually decreased, although still higher than in previous years. Meanwhile, in other locations such as the Gunungsari Dam, Muara Kali Kedurus, and Ngagel/Jagir, COD levels tend to be stable with slight fluctuations. This pattern indicates that the Central Estuary is experiencing more significant organic pollution than other areas, most likely due to human or industrial activities around the area.

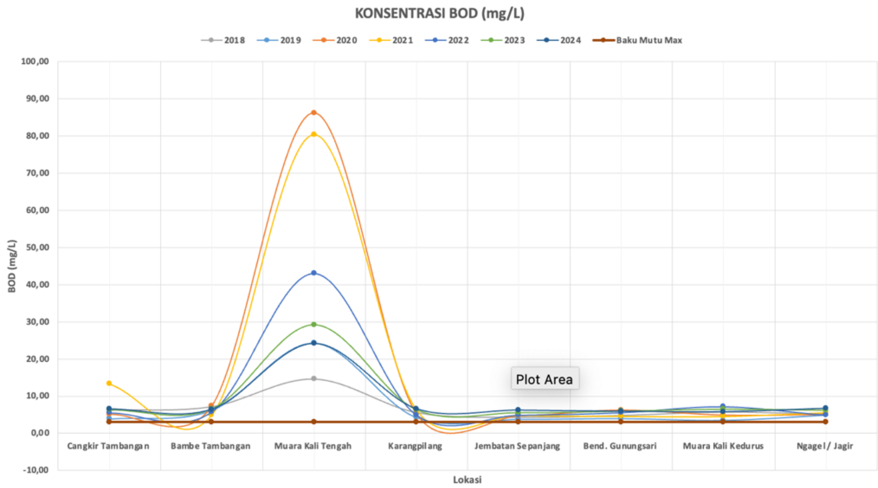

Figure 2. Graph of Water Quality Testing Results of BOD Parameters from 2018 – 2024 (PJTI, 2024)

The graph above illustrates changes in BOD (Biochemical Oxygen Demand) concentrations at several sampling points in the Surabaya River from 2018 to 2024. As with the COD trend, a significant spike was seen in Muara Kali Tengah, with the highest peak in 2020 almost reaching 100 mg/L. After that, the concentration of BOD decreased gradually, although it remained higher than in previous years. Meanwhile, in other locations such as the Gunungsari Dam, Muara Kali Kedurus, and Ngagel/Jagir, the BOD value tends to be stable with slight variation. The sharp increase in the Central Estuary indicates a high level of organic pollution, which is most likely caused by domestic or industrial activities in the surrounding area.

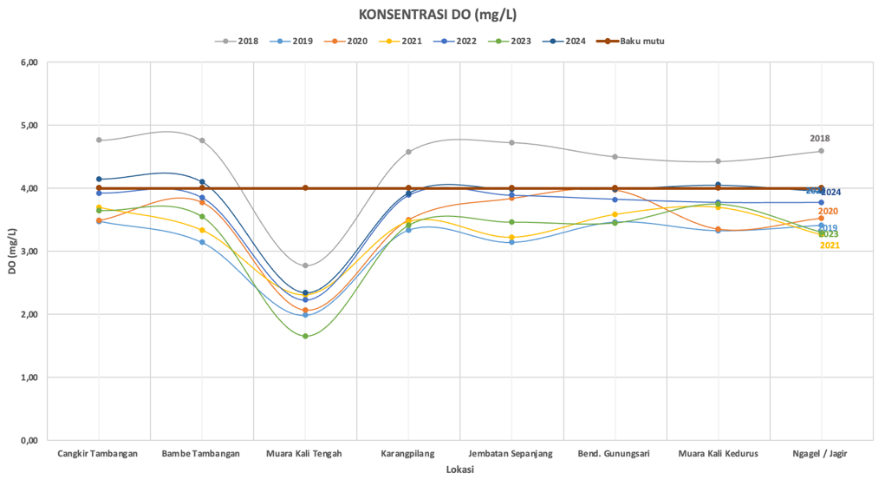

Figure 3. Graph of DO Parameter Water Quality Testing Results from 2018 – 2024 (PJT1, 2024)

The graph above illustrates the variation in dissolved oxygen (DO) levels at various monitoring points of the Surabaya River during the period 2018 to 2024. Overall, it can be seen that DO levels tend to be lower in Muara Kali Tengah than in other locations, with the lowest point occurring from 2020 to 2021. This pattern is contrary to the COD and BOD trends, where high organic pollution in the Central River Estuary causes a decrease in dissolved oxygen due to the increased decomposition process of organic matter. After 2021, DO levels showed a slight increase, although they have not returned to 2018 levels. Meanwhile, in locations such as the Gunungsari Dam, Muara Kali Kedurus, and Ngagel/Jagir, DO levels are more stable with less significant fluctuations. These findings indicate that pollution in Muara Kali Tengah has a considerable impact on oxygen levels in the water, most likely due to domestic and industrial waste in the vicinity.

From the analysis of the three graphs, some of the water quality parameters above which include COD, BOD, and DO show that the water quality at several monitoring points of the Surabaya River, shows that the Central River Estuary is experiencing quite serious pollution. When compared to the class II water quality standard according to Government Regulation No. 22 of 2021, this condition is still far from the permissible threshold. Based on the regulation, class II water should have a maximum COD of 25 mg/L, a maximum BOD of 3 mg/L, and a minimum DO of 4 mg/L. However, the COD graph shows a significant spike in Muara Kali Tengah in 2020, with values exceeding 350 mg/L, indicating high organic pollution, likely coming from domestic and industrial waste. A similar trend is seen in the BOD chart where peak values in 2020 were close to 100 mg/L, well beyond the permissible limits. Meanwhile, the DO graph shows a fairly sharp drop in dissolved oxygen levels at the same location, with the lowest value approaching 2 mg/L, which does not meet the minimum standard for class II. These conditions indicate that high organic pollution has led to a decrease in oxygen levels in the water, which can negatively impact aquatic ecosystems. Water quality in some locations still does not reach the set standards and is likely to worsen in the future. Therefore, intervention from water resource managers and related stakeholders is needed to maintain or improve water quality in the future.

Weighting Weight, Criteria, & Evaluation

In the research of filling out the questionnaire and interviews were carried out to 3 (three) experts each from DLH East Java Province, ITS Environmental Engineering Academics and BOD-2 Natural Resources Management Companies which are expected to have more optimal results. 3 water quality management scenarios are grouped into general conditions, pessimistic conditions and optimistic and optimal conditions. For optimistic conditions that can be implemented, namely Industrial Communal WWTP with a weight of 10.8102 followed by Nanobubble with a weight of 0.6534 and Shipping with a weight of 0.1396. With an optimistic strategy, the Industrial Communal WWTP strategy has the highest value of 10.8102, which shows that this strategy provides a very high value of benefits compared to the existing costs, risks, and opportunities, when assuming all aspects run optimally.

Sensitivity analysis

In testing the resilience and consistency of strategy selection results to changes in weights or assumptions in assessment criteria such as benefits, costs, opportunities, and risks. A sensitivity analysis is carried out with a change in the weight of criteria to assess the level of priority, this sensitivity analysis is important to see whether the chosen strategy remains the best alternative in various scenario conditions, both in general, pessimistic, and optimistic situations.

Sensitivity analysis on several key parameters showed that the priority of the Industrial Communal WWTP strategy was strongly influenced by changes in the weighting criteria, but this strategy remained the preferred choice as long as the weight value was below or near the critical point (±0.4). In contrast, the Nanobubble Generator and Disbursement strategies were relatively stable and were not overly affected by variations in the weight of the criteria, suggesting that the two strategies were less flexible in responding to various changing conditions. Thus, the Industrial Communal WWTP is considered the most resilient strategy and able to adapt to uncertainty in the decision-making process related to water quality management in the Surabaya River.

CONCLUSIONS

This study concludes that the Industrial Communal Wastewater Treatment Plant (WWTP) strategy is the most effective approach for improving water quality in the *Surabaya River*, as it achieved the highest priority score in the ANP-BCOR analysis under optimistic scenarios. By integrating multi-criteria decision-making tools, the research provided a comprehensive evaluation of benefits, costs, opportunities, and risks, emphasizing the importance of a holistic water resource management approach. Although nanobubble technology and periodic discharge showed potential, their impact was less significant compared to the scalable and sustainable communal WWTP solution. The findings highlight the necessity for collaborative efforts among government agencies, industries, and local communities to ensure effective implementation. Future research should investigate the long-term environmental and socio-economic effects of these strategies, explore the integration of emerging technologies such as AI-driven monitoring and nature-based solutions, and incorporate a wider range of stakeholder perspectives and regional contexts to enhance the robustness and applicability of the decision-making framework.

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