Saprobic Trophic Approach as a Biological Indicator for Eutrophication Management in Cengklik Reservoir, Boyolali, Central Java

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Abstract. Eutrophication is a serious environmental problem in tropical reservoirs, triggered by human activities like floating net cages and agriculture activity. Its consequences, such as massive water hyacinth growth, directly threaten sustainable water resources and impede the achievement of SDGs 6 and 14. This study assessed the saprobic trophic approach as a sensitive indicator for monitoring eutrophication in Cengklik Reservoir, Boyolali. Analysis utilized secondary water quality data (DO, BOD, nitrate, and phosphate) to evaluate the organic pollution load. Results indicated the reservoir water conditions tend to be mesosaprobic and chronic eutrophication confirming a moderate to high organic pollution load. Strong correlations were found between high nitrate/phosphate concentrations and the observed saprobic levels, supporting the visual evidence of abundant water hyacinth. The saprobic trophic approach is confirmed as an effective biological indicator that complements water chemistry. Long-term trend data (BOD, DO, Nitrate, Phosphate 2020-2024) is an innovative decision support tool for water resource monitoring and management. Policy and governance implications: this swift, ecological indicator provides crucial data for evidence-based decision-making and stricter pollution control policies on nutrient discharge. Routine monitoring with this approach is vital for achieving sustainable water governance and supporting SDGs 6.3 (water quality) and 14.1 (nutrient pollution reduction) in the Cengklik Reservoir.

1 Introduction

Water is an essential resource that supports life, and its availability in both adequate quantity and quality is a crucial issue today. In Indonesia, reservoirs and lakes play a vital role as multipurpose infrastructure, providing raw water for domestic and industrial needs, supporting the agricultural sector through irrigation, and serving as centers for tourism and fisheries [1]. Amidst rapid population growth and the intensification of human activities, aquatic ecosystems face serious biological pressures, one of which is eutrophication. Eutrophication is the excessive enrichment of nutrients, particularly phosphorus and

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nitrogen, in a body of water . It is caused by domestic waste, fertilizer runoff from agricultural activities, and residual feed and fish waste from fisheries, especially floating net cages. This phenomenon triggers an explosion in the algal population and ultimately disrupts the ecosystem's balance, drastically reducing water quality **[**2**]**.

One of the most prominent visual manifestations of eutrophication is the uncontrolled growth of water hyacinth (Eichhornia crassipes). This plant can massively cover the water's surface, blocking sunlight penetration, reducing dissolved oxygen (DO) levels, and inhibiting water circulation [3]. Many reservoirs in Indonesia face this issue, including Cengklik Reservoir. As a multipurpose reservoir that also supports large-scale floating net cage activities, Cengklik Reservoir faces ecological pressure. The high intensity of floating net cages causes the accumulation of organic and inorganic matter, accelerates the rate of sedimentation, and directly contributes to increased nutrients that trigger water hyacinth growth. This condition threatens the sustainability of the reservoir's function and the well-being of the local communities that depend on its water resources [4].

Most water quality monitoring in Indonesia tends to focus on analyzing physical and chemical parameters such as BOD, COD, DO, and pH. While this method is important for directly measuring water conditions, it often fails to provide a complete and continuous picture of the aquatic ecosystem's health. The rapid fluctuation of physical-chemical data can make it difficult to determine long-term ecological conditions [5]. Therefore, a more holistic and innovative monitoring approach is needed that can integrate biological data as an indicator sensitive to environmental changes.

Previous studies have extensively discussed water quality but have focused only on physical-chemical parameters. There are still very few that specifically use a saprobic-trophic approach to link it to the problems of eutrophication, agriculture activity and floating net cages in tropical reservoirs like Cengklik Reservoir.

This study utilizes and examines the saprobic-trophic approach as an alternative solution for more comprehensive water quality monitoring. This approach is based on an analysis of aquatic organism communities, especially phytoplankton, zooplankton, and benthos, which act as sensitive bioindicators of organic pollution. These organisms naturally group themselves based on their tolerance to organic loads. This allows us to classify water conditions from a clean level (oligosaprobic) to a very polluted level (polisaprobic) [6]. But in this study conventional methods (BOD, DO) reflect saprobic conditions (organic pollution) and nutrients (nitrate, phosphate) reflect the trophic conditions of the waters, this study defines the "Saprobic Trophic Approach" as an effort to integrate data from both indicators (physicochemical) in assessing pollution status.

By analyzing secondary water quality parameter data, this study aims to analyze and compare the saprobic and trophic status in the Cengklik reservoir through long-term assessment of key physicochemical indicators (BOD, DO, nitrate and phosphate), identify trends and temporal dynamics of key nutrient concentrations that drive eutrophication and verify its visual impact through supporting evidence such as water hyacinth proliferation, formulate data-based management and policy implications as an innovative approach in supporting decision-making for sustainable eutrophication control of the Cengklik reservoir.

2 Materials and Methods

This study is a descriptive analysis using a case study approach. The data used in this study is secondary data. Therefore, this research did not involve primary data collection in the field but utilized secondary data from official sources. The data sources for this study are official reports from the BBWS (Balai Besar Wilayah Sungai) Bengawan Solo website, which is updated monthly with laboratory parameters of water quality and field data on water quality, such as rainfall, current, and discharge. Other secondary data used in this study are scientific publications from previous research that specifically examine water quality in Cengklik Reservoir. The water quality parameters analyzed in this study include BOD (Biological Oxygen Demand), DO (Dissolved Oxygen), phosphate, and nitrate content, as well as other data in the form of visual observations of the water hyacinth condition in Cengklik Reservoir. The data analyzed in this study are historical BOD, DO, phosphate, and nitrate data over a five-year period (2020-2024).

Data analysis was carried out by collecting the secondary data and then processing it descriptively using tables and graphs to show the trends and conditions of water quality in Cengklik Reservoir, Central Java. The application of the saprobic-trophic concept is based on an interpretation of the water quality parameters, especially BOD and nutrients, which are conceptually related to the level of organic pollution. This analysis will link the physical-chemical conditions of the water with the appropriate saprobic classification. The limitation of this study is that the data used is only secondary data, so it is recommended that primary plankton/ benthos samples be taken in the future.

3 Results and Discussion

3.1 Cengklik Reservoir Water Quality Based on Secondary Data

Table 1. Description of Cengklik Reservoir Water Quality Parameters 2020-2024

Parameter	Units	Year	n	Min	Max	Mean	Quality Standard (Class II)
BOD	mg/L	2020	10	4,2	14,8	7,9	**3mg/L**
		2021	12	2,87	13,3	5,6	
		2022	12	1,5	11,6	4,2	
		2023	12	1,7	11,1	3,4	
		2024	12	1,97	25,2	6,2	
DO	mg/L	2020	10	0,4	5,96	3,11	**≥4mg/L**
		2021	12	1,3	8,4	3,90	
		2022	12	0,8	6,4	3,12	

Parameter	Units	Year	n	Min	Max	Mean	Quality Standard (Class II)
		2023	12	1,8	6,6	4,26	
		2024	12	2,06	6,26	4,51	
Nitrat	mg/L	2020	10	0,04	2,92	7,47	**10 mg/L**
		2021	12	0,008	0,82	0.17	
		2022	12	0,03	0,49	0,11	
		2023	12	0,1	0,77	0,22	
		2024	12	0,005	12,30	2.25	
Phosphate	mg/L	2020	10	0,003	20,07	2.755	**0,2 mg/L**
		2021	12	0,0019	1,061	0,476	
		2022	12	0,008	1,36	0.496	
		2023	12	0,009	0,178	0,107	
		2024	12	0,062	0,31	0,206	

Table 1 above presents water quality data in the Cengklik Reservoir. Based on Government Regulation Number 22 of 2021 concerning the Implementation of Water Quality Protection and Management, the BOD value in the last 5 years has exceeded all quality standards, namely more than 3 ml/L. The highest BOD value reached 7.9 mg/L in 2020. The lowest BOD value reached 3.4 mg/L in 2023. Although the BOD value in 2023 was the lowest value, it still exceeded the quality standard value required by Government Regulation Number 22 of 2021 concerning the Implementation of Water Quality Protection and Management. High BOD values indicate that the waters contain a lot of organic material that can be decomposed by microorganisms. This condition indicates high organic pollution and can reduce dissolved oxygen (DO) levels in the water, thereby endangering the lives of organisms and causing a decline in water quality.[7]

The dissolved oxygen (DO) content in the last 5 years (2020-2024) also showed low values because all DO values were close to the lower limit of the quality standard, which is >4 mg/L. The highest DO value in the last 5 years was only 4.51 mg/L in 2024. This indicates low oxygen availability in the waters because even though the content was more than 4 mg/L, it was still too close to the quality standard. The lower the DO, the more oxygen in the water is used by microorganisms to decompose organic matter in the water. So the higher the BOD value, the lower the DO value will also be.[7]

In the past five years, nitrate levels in the Cengklik Reservoir have remained below the standard, at less than 10 mg/L. The highest nitrate level was recorded in 2020 at 7.47 mg/L, but this remains below the standard. Nitrate is primarily sourced from human activities such as fertilizer runoff, wastewater, and livestock manure. High nitrate levels in the water cause eutrophication, which is excessive algae growth in reservoirs/lakes.[8].

Phosphate in water should also not exceed the quality standard value of Government Regulation No. 22 of 2021 (the limit is 0.2 mg/L in water). Over the past 5 years, the average phosphate level in the waters of the Cengklik Reservoir has exceeded the required quality standard. In 2020, phosphate levels reached 2.75 mg/L. Excessive phosphate levels can also cause eutrophication, resulting in uncontrolled algae (water hyacinth) growth, depleting oxygen, and endangering the lives of other aquatic organisms. Excess phosphate in water is caused by human activities such as fertilizer use, water runoff, and industrial waste disposal.[9]

3.2 Interpretation of Saprobic and Eutrophication Levels

Based on existing water quality data, the ecological conditions of the Cengklik Reservoir can be interpreted using a saprobic trophic approach. High levels of phosphate and nitrate indicate that the reservoir waters have experienced eutrophication, namely nutrient enrichment that causes a fertile ecosystem. In a saprobic trophic context, this condition indicates waters rich in organic matter, a characteristic of the β-mesosaprobic to α-mesosaprobic zones.[10]

In the ß-mesosaprobic zone, the waters have a moderate level of organic pollution. This is characterized by a decrease in biodiversity and the dominance of tolerant organism species. The high BOD (Biological Oxygen Demand) value and abundant nutrient concentrations in the Cengklik Reservoir can be classified into α-mesosaprobic conditions. This zone indicates a more severe level of pollution, where the waters are dominated by bioindicator species that are very tolerant to organic pollution. [10]. This condition is directly correlated with the growth of aquatic weeds such as water hyacinth, which indicates an uncontrolled nutrient supply, resulting in the water hyacinth bloom phenomenon in the Cengklik Reservoir. The condition of the waters classified as α-mesosaprobic based on water quality data analysis is visually reflected in the vast expanse of water hyacinth as in Figure 1 below.

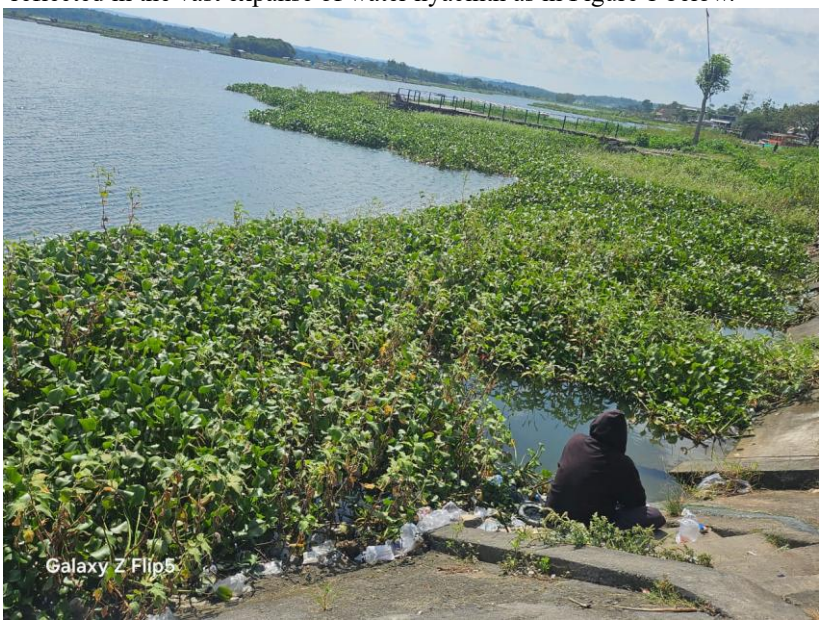

Fig.1. The surface of the Cengklik Reservoir, covered in water hyacinth, reflects the phenomenon of eutrophication. Source: Author's Documentation, 2025

3.3 The Relationship Between Floating Net Cages, Saprobic and Eutrophication

The pollution load identified in the water quality data analysis is closely related to the activity of floating net cages. Leftover fish feed and metabolic waste (fish excrement) from floating net cages are the primary sources of organic matter and nutrients entering the reservoir ecosystem. The organic matter is then decomposed by microorganisms, which consume dissolved oxygen (DO) and increase BOD levels.

Consequently, nutrients in the form of phosphate and nitrate from this waste act as fertilizer, fueling the rapid growth of phytoplankton and aquatic weeds. Therefore, the increased saprobic levels indicated by the water quality data directly reflect the impact of floating net cage activity. The saprobic conditions found are conceptually consistent with the dominance of water hyacinth as a visual indicator of eutrophication. [11]. This demonstrates that the saprobic trophic approach, even based on bioindicators, can be effectively used to interpret physicochemical data to understand the health of aquatic ecosystems.

3.4 Conceptual Diagram Illustrating the Linkages between Anthropogenic Activity (Floating Net Cages), Saprobic Trophic, and Eutrophication in Cengklik Reservoirs

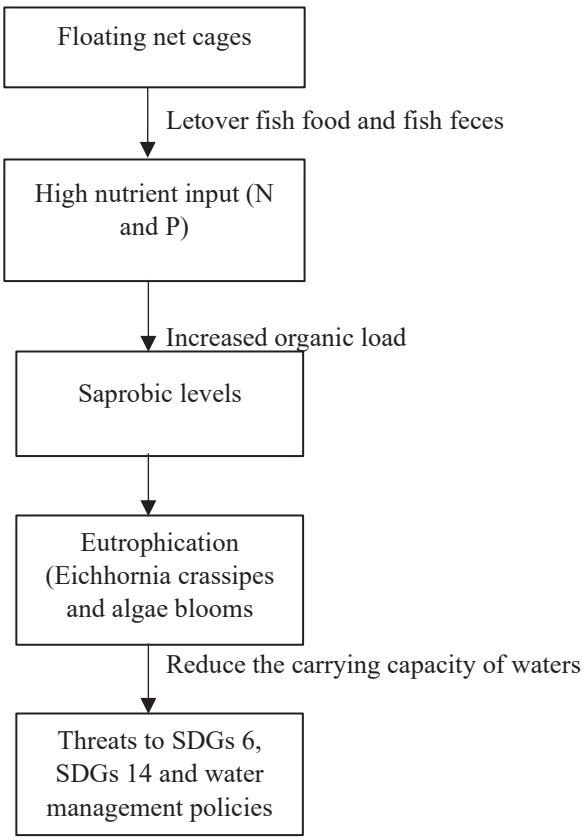

Fig.2. Conceptual Diagram Illustrating the Linkages between Anthropogenic Activity

Figure 2 presents a conceptual pathway that illustrates the causal relationship between anthropogenic activities and measured saprobic trophic status. This conceptual framework positions the Saprobic Trophic Approach as an important ecological diagnostic tool. It successfully translates operational scale into measurable and quantifiable environmental impacts, providing policymakers with clear, evidence-based justification for enforcing stricter regulations on nutrient discharges and promoting sustainable water governance. The main source of pollution is the floating net cage activity in the reservoir. The floating net cage activity results in uneaten fish food and fish feces entering the reservoir water. This results in high nutrient input (N and P), thus causing an increase in the organic load. The increase in organic load is a cause that leads to saprobic conditions. Saprobic conditions will accelerate the manifestation of eutrophication (algal blooms and water hyacinth). This will reduce the water's carrying capacity and threaten SDGs 6, SDGs 14 and water management policies.[12]

3.5. Policy Implications and Contribution to Sustainable Development Goals

Our findings, indicating that Cengklik Reservoir is in a mesosaprobic state due to high organic and nutrient loading, carry significant implications for water resources management and national sustainability efforts. The effectiveness of the Saprobic Trophic Approach provides a robust tool to address complex environmental governance challenges.

3.5.1 linkage to sustainable development goals/SDGs 6 (clean water and sanitation)

The measured degradation of water quality in Cengklik Reservoir directly impedes the achievement of 6 (Clean Water and Sanitation), particularly Target 6.3 which aims to improve water quality by reducing pollution. Given the reservoir's function as a vital raw water source, the established mesosaprobic condition poses a risk to both human health and local ecology.

Implementing the Saprobic Trophic Approach contributes to the required routine monitoring of ambient water quality. This approach provides a sensitive and rapid biological early warning system, offering decision-makers timely, objective data to track the effectiveness of pollution mitigation strategies. Integrating this indicator strengthens sustainable water governance and supports Indonesia's progress reporting towards.[13]

3.5.2 Relevance to SDGs 14 (Life Below Water /Adapted for Inland Waters)

While 14 traditionally focuses on marine ecosystems, its principles are highly relevant and adaptable to large inland water bodies like Cengklik Reservoir. Specifically, Target 14.1 mandates the prevention and reduction of pollution of all kinds, including nutrient pollution from land-based activities. Our study establishes a strong correlation between saprobic levels and nitrate/phosphate concentrations, confirming that eutrophication in Cengklik is a clear manifestation of this land-based nutrient loading.[2]

The use of the saprobic indicator supports the spirit of 14 by helping to diagnose the severity of ecological degradation that leads to biodiversity loss and habitat disruption. By providing an effective metric to protect ecological integrity, this study supports the conservation and sustainable utilization of freshwater resources. [2]

3.5.3 Indonesian Policy on Floating Net Cage Management

The nutrient pollution diagnosed by the saprobic approach is strongly linked to the operation of Floating Net Cages, which is strictly regulated by Indonesian national policies (e.g.,

Minister of Public Works and Housing Regulation No. 7 Year 2023). Our results provide the crucial scientific justification required for the implementation and enforcement of these existing regulations. [14]

The Saprobic Trophic Approach can serve as the ecological basis for:

1. Enforcing Carrying Capacity Limits: The measured mesosaprobic status acts as a clear ecological threshold, supporting policies that mandate the restriction or rationalization of unit numbers to align with the reservoir's compromised carrying capacity.
2. Effective Monitoring: This biological indicator provides an objective measurement of the ecological impact of waste (uneaten feed and feces). This data is essential for the routine monitoring and evaluation protocols conducted by reservoir managers, thereby supporting effective governance and targeted regulatory intervention.[15]

Ultimately, integrating this sensitive biological indicator will enable authorities to transition from a reactive pollution response to a proactive and sustainable management model, securing the long-term, multi-functional use of Cengklik Reservoir.

Long-term water quality assessment (2020-2024) using key physicochemical indicators provides a critical database for reservoir managers. Observing 5-year water quality trends is an innovative approach to monitoring because momentary studies often fail to capture the dynamics of ongoing pollution. Trend analysis shows an increase in phosphate in the Cengklik reservoir, which on average exceeds the quality standard (0.2 mg/L) in 2020, 2021, 2022, and 2024. This increase in phosphate is a major stressor leading to chronic eutrophication. This is evidenced by the presence of water hyacinth blooms in the reservoir, which threaten the reservoir's hydrological and socio-economic functions.

Reservoir managers must immediately establish regulations for the use of non-organic fertilizers in upstream areas and buffer zones along the reservoir's edge. This policy is based on the finding of phosphate trends exceeding quality standards in the last 4 years, not just a temporary result. In addition, a structured bioremediation program or water hyacinth harvest is needed as a short-term action to reduce biomass and restore DO (Demand Oxygen) function due to high BOD. For the long term, a comprehensive pollution load audit is needed in the upstream area to identify non-point source pollution sources. Long-term data (2020-2024) is an effective Decision Support tool to achieve Sustainable Water Management (in accordance with SDGs 6) and not just a water quality report.

4 Conclusion

Based on the secondary data analysis and conceptual interpretation, this study concludes that the saprobic trophic approach has great potential as an effective biological indicator for monitoring eutrophication in reservoir waters such as the Cengklik Reservoir. Water quality data analysis indicates that the waters of the Cengklik Reservoir have degraded and can be classified as β-mesosaprobic to α-mesosaprobic. This condition is strongly supported by visual evidence in the form of massive water hyacinth growth, a clear manifestation of eutrophication. The primary cause of this water quality decline is poorly controlled floating net cage activities, agricultural activities that produce fertilizer and pesticide residues which contribute to excessive organic and nutrient pollution loads in the reservoir ecosystem.

A long-term water quality assessment (2020-2024) using a trophic saprobic approach (represented by the integration of BOD/DO and phosphate/nitrate data) confirmed chronic eutrophication in the Cengklik reservoir. A 5-year data trend analysis showed a substantial

increase in phosphate, which drives water hyacinth proliferation and threatens reservoir function. This study contributes to an innovative decision support tool where long-term data serves as an early warning signal for management. The recommendations from this study, with key policy implications for reservoir managers, include strict regulation of fertilizer and waste use upstream, restrictions on the number of floating net cages, water hyacinth biomass remediation measures, and the establishment of ecological buffer zones. These data-driven measures are crucial for achieving sustainable water resources management.

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