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Assessing Seasonal Variations in Reservoir Water Quality: Implications for Eutrophication and Pollution Management

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Abstract. Surface water is a strategic freshwater reserve that meets the needs of households, agriculture, livestock, industry, and research. Surface water quality is affected by anthropogenic activities and seasonal variations, which can pose ecological risks. This study aimed to assess the water quality of the Darma Reservoir, the status of water quality and trophic levels, and trends in water quality changes in the rainy and dry seasons. The study was conducted for one year, from October 2023 to September 2024, covering the rainy and dry seasons. Sampling was carried out at eight stations spread across three zones of the Darma Reservoir, namely the inlet zone, utilization zone, and outlet zone. Water quality parameters were tested using PCA, the water sample measurements were compared with water quality standards (PP/22/2021), and the Regulation of the Minister of State for the Environment number 28 of 2009 was analyzed using the STORET index. The results of the study showed differences in water quality characteristics between seasons, where the concentration of Total Nitrogen (TN) showed an increase in the rainy season, while the concentration of Total Phosphate (TP) was higher in the dry season.

Key words : eutrophication, nutrient supply, water management, seasonal variation, pollution sources

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1. Introduction

Surface water is a water source that is easily accessible and can be found anywhere. This water has a strategic function , because it meets most of the water needs such as drinking and domestic needs, industry and research, irrigation and agricultural production, horticulture, livestock, and management of aquatic life including fish and fisheries (1) . However, anthropogenic activities caused by urbanization , industrialization and agricultural production activities have caused a decrease in the quality and scarcity of surface water (2). This condition is worsened by efforts to improve the quality of surface water that are not yet optimal (3).

Poor surface water quality will impact eutrophication, which is responded to by the growth of various aquatic plants. These plants can live submerged in water or partially emerge to the surface of the water and float freely on the surface of the water (4). These aquatic plants often become invasive species, causing an imbalance in the surface water ecosystem. Eutrophication increases the growth rate of aquatic plants (5), including water hyacinth (6), whose growth is very difficult to control. (7) . This is a challenge for various efforts to maintain and improve water quality in a flexible system. (8) Increase in human population and economic activity, especially in the agricultural sector, with excessive use of fertilizers and wastewater discharge into water bodies, causing disaster for aquatic ecosystems (9). Runoff and erosion of agricultural land cause an increase in nutrients and organic matter in water bodies. (10).

Surface water quality is essential as a life support. Water pollution on a global scale has caused significant ecological problems (11). Polluted water hurts public health, economic stability, agricultural productivity, availability of drinking water, and biodiversity (12). Suboptimal surface water management is a serious problem in developing countries (3). One of the surface water resources is a reservoir built for a specific purpose. The function of the reservoir as a habitat for various aquatic plants (13); (14) ecosystem service providers (15); (16) and tourism (17). The reservoir ecosystem is influenced by anthropogenic activities around the reservoir and along the river basin and natural phenomena that affect water quality (18). Communities along the river use the river to dispose of domestic waste without processing (19); (20). The quality of reservoir water as a surface water resource dramatically affects the productivity of aquatic organisms. beneficial for human life (21). Reservoir ecosystems are more susceptible to accumulating nutrients, organic matter, suspended solids, and sedimentation (22).

Darma Reservoir is a tropical reservoir surrounded by villages in the Darma District, Kuningan Regency, West Java, located at latitude S$7^0$0'15.264” and longitude 108^0 24'33.354” with an altitude of 712 meters above sea level. The area is 344.95 Ha with a maximum water volume of 37,850,000 m 3. The highest water area reaches 342.26 Ha Ha, and the lowest is 280.35 Ha, with an average depth of 12 m. Reservoir water is used for raw water for drinking water, recreation, freshwater fish farming, and agricultural irrigation. Agriculture is part of the agrarian culture of the people around the Darma Reservoir, and KJA fish farming is the economy’s primary driver. Considering its strategic benefits, the quality of the Darma Reservoir waters is important. However, various anthropogenic activities around the reservoir threaten the stability of water quality. Domestic waste and liquid waste are one of the threats to surface water (23). Poor water quality causes economic losses and can potentially affect human health (24).

Assessing the water quality of Darma reservoir is one of the actions that can be taken to control pollution and support its sustainable management. Therefore, studying water quality covering physical, chemical, and biological parameters requires temporal time variations in the rainy and dry seasons to obtain comprehensive data. The assessment results can help managers know the cause of the pollution so that the right decision can be taken to mitigate eutrophication and manage pollution sources. Therefore, this study aims to assess surface water quality in the Darma reservoir, including physical, chemical, and biological parameters, in the dry and rainy seasons. It is also important to know the ecological risks caused by the poor quality of the Darma reservoir water through a study of determining water quality and trophic status levels so that it can be a reference for reservoir management in the trophic region. The findings of this study can inform decision-makers about the dangers of utilizing polluted surface water, so it is important to make the right decisions for sustainable reservoir management.

2. Research methods

The study was conducted in the Darma Kuningan Reservoir, West Java, Indonesia, with an area of 344.95 Ha. Water sampling was carried out at eight research stations covering the inlet zone (Cisanggarung, Cireungit, and Darmaloka Rivers), the middle zone (floating net cages, tourism, PDAM raw water) and the reservoir outlet (**Figure 1**). The study was conducted for one year (October 2023-

September 2024) during the dry season (October, November 2023, May-September 2024) and the rainy season (December 2023, January-April 2024).

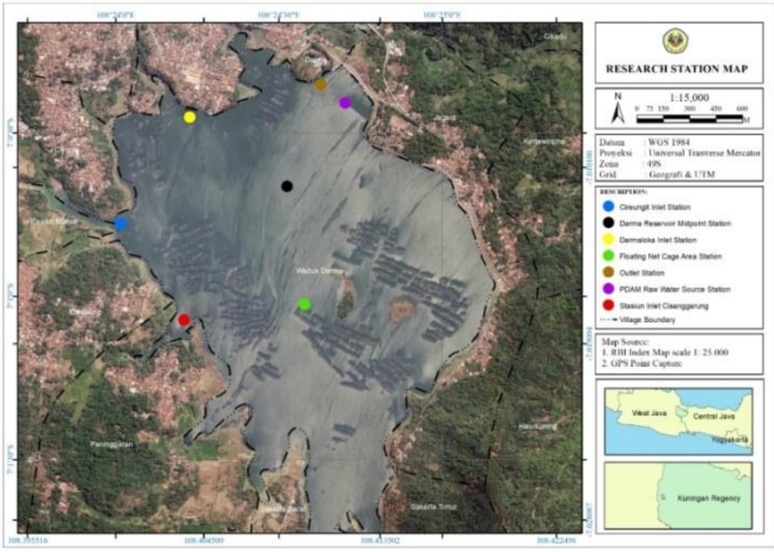


Figure 1. Darma Reservoir Research Station

Tools and materials

The study used water sampling tools, in-situ and ex-situ water quality testing tools, and transportation tools. Water samples for test materials were taken using a horizontal water sampler, put into a glass bottle container, added HNO_3, H_2SO_4, and NaOH as needed, and stored in a cooler box. In-situ water quality testing used a thermometer, TDS meter, TSS meter, pH meter, and DO meter. Ex-situ testing, namely Total Nitrogen, Total Phosphate, BOD, COD, and Total Coliform was carried out in the laboratory. Water sampling refers to SNI 6989.57:2008. The means of transportation for water sampling from each research station was a motorboat.

Research stages

The study began with a preliminary survey to determine the location of the water sampling station. The next step was a field survey to measure water quality parameters (**Table 1)** at eight stations. Water sampling was carried out every month in the first week. The water sampling method was *in-situ* to obtain data on air temperature and humidity, water clarity, temperature, pH, TDS, TSS, and DO. Furthermore, water samples were taken for *ex-situ* laboratory testing at the Sucofindo Cirebon laboratory.

Table 1. Parameters and Methods of Water Quality Testing

No.	Parameter	Unit	Method	Water Quality Classification			
				I	II	III	IV
	Physics						
1	Temperature (on site)	^0C	2550 B	Dev 3	Dev 3	Dev 3	Dev 3
2	Total Dissolved Solids (TDS)	mg/l	2540 C	1,000	1,000	1,000	1,000
3	Total Suspended Solids (TSS)	mg/l	2540 D	25	50	100	400
	Chemistry:						
4	pH (on site)	-	4500-H^+-B	6-9	6-9	6-9	6-9
5	Total Nitrogen (TN)	mg/l	PO/CBN-LAB.Air/43	0.65	0.75	1.9	-
6	Total Phosphate (TP)	mg/l	4500-PC	0.01	0.03	0.1	-
7	BOD	mg/l	APHA 5210 B	2	3	6	12

8	COD	mg/l	PO/CBN/LAB.AIR/22	10	25	40	80
9	Dissolved Oxygen (DO) (on site)	mg/l	4500-0-B	6	4	3	1
	Biology						
10	Total Coliform	CFU/100 ml	9222 B	1,000	5,000	10,000	10,000

Source: Sucofindo Environmental Laboratory (2023)

Determination of key factors

Water quality parameters in the dry and rainy seasons were analyzed using multivariate statistical analysis using *Principal Components Analysis* (PCA). One advantage of PCA is the ability to analyze a large number of variables from research stations (25).

Determination of surface water quality

Determined by comparing physical, chemical, and biological parameters with the Government Regulation of the Republic of Indonesia (PPRI) number 22 of 2021. Four water quality classification standards are determined: class A for drinking water, class B for water recreation, class C for aquaculture, and class D for irrigation (**Table 1**). Water quality status is determined using the STORET method (**Table 2)** with the US-EPA value system (26) to determine the water quality category (**Table 3**), which refers to the Regulation of the Minister of Environment of the Republic of Indonesia number 115 of 2003. The STORET method can determine various parameters that meet or exceed water quality standards according to their designation. (27).

Table 2. Determination of water quality status value system

Number of samples	Mark	Parameter		
		Physics	Chemistry	Biology
< 10	Maximum	-1	-2	-3
	Minimum	-1	-2	-3
	Average	-3	-6	-9
≥ 10	Maximum	-2	-4	-6
	Minimum	-2	-4	-9
	Average	-6	-12	-18

Table 3. US - UEPA water quality classification

Score	Class	Water Quality Conditions
0	A (very good)	Meet quality standards
-1 to -10	B (good)	Lightly contaminated
-11 to -30	C (medium)	Moderately contaminated
≥ -31	D (bad)	Heavily contaminated

Determination of trophic status

Determined based on the concentration of TN and TP parameters and water transparency based on the Regulation of the Minister of State for the Environment number 28 of 2009 concerning the capacity of water pollution loads in lakes and/or reservoirs. A study of the trophic status of waters is needed to control eutrophication and sustainable reservoir management (28). Increased concentrations of TN and TP caused by anthropogenic activities from outside and inside the waters cause increased eutrophication (29). The criteria for the trophic status of the Darma Reservoir can be seen in **Table 4.**

Table 4. Reservoir Trophic Status Criteria

Trophic Status	Average Level (mg/L)		Average Brightness (m)
	Total N	Total P	
Oligotrophic	≤ 0.65	< 0.01	≥ 10
Mesotrophic	≤ 0.75	< 0.03	≥ 4
Eutrophic	≤ 1.9	< 0.1	≥ 2.5
Hypereutrophic	≥ 1.9	≥ 0.1	< 2.5

3. Results and Discussion

Parameters analyzed in the dry and rainy seasons are extracted to obtain the parameters that most affect the water quality of the Darma reservoir using PCA. The results of the PCA analysis show that the parameters of Total Nitrogen (TN), *Dissolved Oxygen* (DO), *Biological Oxygen Demand* (BOD), and pH are the first main components that affect the water quality of the Darma Reservoir (Figure 2). The parameters of Total Phosphate (TP) and TDS are the second main components that affect the condition of water hyacinth biomass. PCA analysis of the main water quality parameters includes the Darma Reservoir water's physical, chemical, and biological parameters.

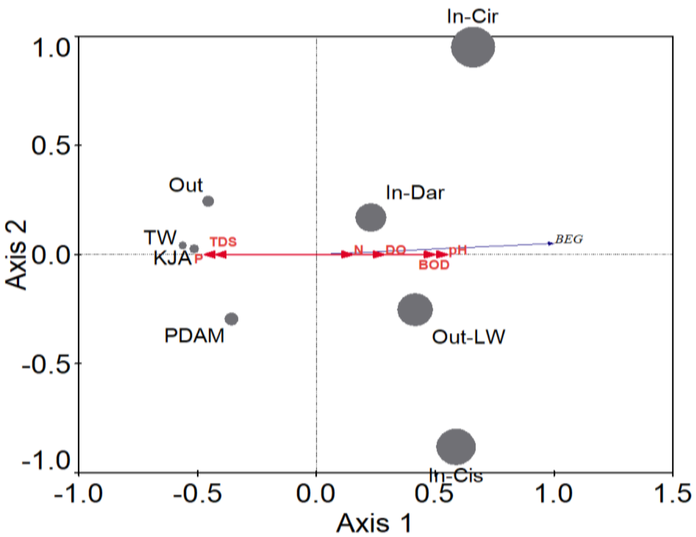


Figure 2. PCA Analysis of Darma Reservoir Water Quality with Distribution of Research Stations

The study's results in the rainy and dry seasons provide more information on water quality and negative environmental impacts. Rainfall data for 2023 and 2024 (**Table 5)** were taken from the Darma Dam Post, Cimanuk-Cisanggarung River Basin Center (BBWS).

Table 5. Rainfall and Area of Water Pool of Darma Reservoir

No.	Month	Year	Rainfall (mm/month)	Reservoir Water Area (Ha)	Percentage of Inundation (%)	Information
1	October	2023	0	284.93	83	Drought
2	November	2023	56.5	303.68	88	Drought
3	December	2023	143.5	280.35	81	Rain
4	January	2024	447.5	333.41	97	Rain
5	February	2024	459	327.69	95	Rain
6	March	2024	516	330.6	96	Rain

7	April	2024	267	342.26	99	Rain
8	May	2024	91	337.64	98	Drought
9	June	2024	17.5	327.32	95	Drought
10	July	2024	80	321.25	93	Drought
11	August	2024	0	330.63	96	Drought
12	September	2024	32	334.08	97	Drought

Source: BBWS-PBD, 2023-2024

3.1. Rainy Season Water Quality

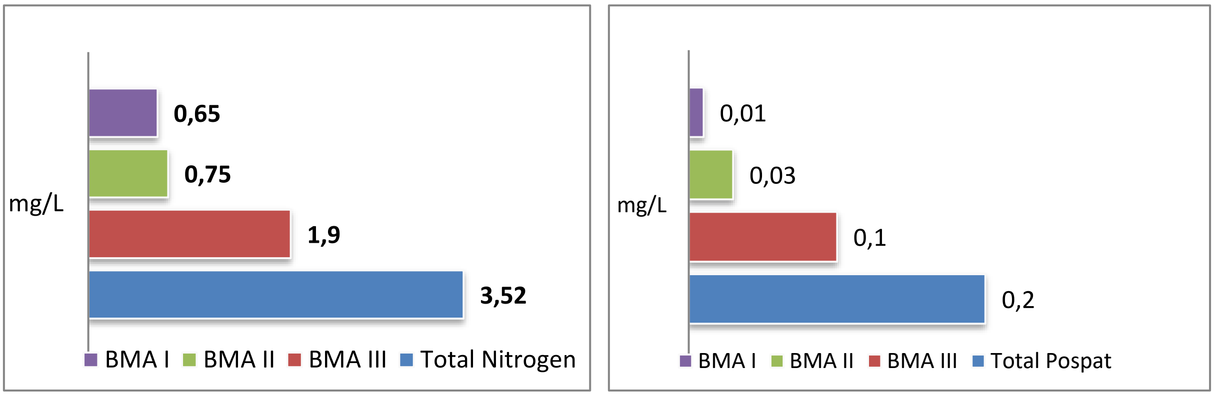
The rainy season in 2023 will last for 5 months, starting from December 2023 to April (**Table 5)**. Based on the results of the physical parameter test, the average water temperature of the Darma Reservoir is 27.75 0 C with a concentration of dissolved particles (TDS) of 76.67 mg/L and suspended particles of 94.08 mg/L. The complete results of the chemical and biological parameter tests are presented in **Table 6.**

Table 6. Darma Reservoir Water Quality in the Rainy Season

No.	Parameter	Unit	Average value	Water Quality Classification (PP-22-2021)			
				I	II	III	IV
	Physics:						
1	Temperature	mg/L	27.75	Dev 3	Dev 3	Dev 3	Dev 3
2	TDS	mg/L	76.77	1,000	1,000	1,000	1,000
3	TSS	mg/L	94.08	25	50	100	400
	Chemistry:						
4	pH		7.39	6-9	6-9	6-9	6-9
5	Total Nitrogen (TN)	mg/L	3.52	0.65	0.75	1.9	-
6	Total Phosphate (TP)	mg/L	0.20	0.01	0.03	0.1	-
7	BOD	mg/L	10.45	2	3	6	12
8	COD	mg/L	34.83	10	25	40	80
9	DO	mg/L	1.21	6	4	3	1
	Biology:						
10	Total Coliform	CFU/100 ml	900.00	1,000	5,000	10,000	10,000
	Total STORET Index Score			-116	-110	-78	0
	Water Quality Status			Heavily Polluted	Heavily Polluted	Heavily Polluted	Meet Quality Standards

Note: average air temperature 28.43 ^{0}C

It is noted in this study (**Table 6**) that the physical parameters of the average test value of water temperature during the rainy season do not exceed the water quality standards stipulated in Government Regulation Number 22 of 2021. Meanwhile, the TSS concentration does not meet the Water Quality Standards (BMA) class I and II, so it is unsuitable for raw drinking water and water recreation facilities/infrastructure. The chemical parameters in this study, only pH, are following BMA. TN, TP, BOD, COD, and DO concentrations do not comply with BMA. Total Coliform as a chemical parameter tested in this study is still below BMA. The water quality of the Darma Reservoir is included in the class D category (poor) with heavily polluted water quality conditions for Classes I, II, and III, while class IV still meets BMA standards (**Figure 3**).



(a) **(b)**

Figure 3: (a) TN Concentration in the Rainy Season; **(b)** TP Concentration in the Rainy Season

The rainy season is the farming season, during which farmers around the Darma Reservoir carry out various agricultural activities. Chemical fertilizers such as Nitrogen, Phosphate, Potassium (NPK), urea, and manure are used more to increase crop yields. Rainwater carries unabsorbed fertilizer runoff from river flow to reservoirs, including domestic wastes, causing TP concentrations to exceed BMA. Domestic liquid waste containing a lot of detergents and animal waste contributes to high TP concentrations. Reservoirs are important absorbers of sediment and are indicators of the total load of organic and inorganic pollutants throughout the catchment (30). Pollutants are caused by rainwater, topography, domestic waste, livestock, and industry (31). River currents that pass through urban and rural areas carry pollutants to lakes or reservoirs (32), resulting in high levels of reservoir vulnerability to pollution that causes eutrophication (33).

High organic and inorganic content in reservoir water, such as agricultural, domestic, and KJA cultivation waste decomposed by microorganisms, will increase BOD and COD values (34). The decomposition of organic and inorganic materials by microorganisms uses oxygen dissolved in water, decreasing DO concentration in reservoir water. Dissolved oxygen in water is a limiting factor for the growth of aquatic organisms, especially in fish cultivation (35). Agricultural land cultivation in the upstream part of the river and utilization of Darma Reservoir sediment land and KJA cultivation are the main factors causing changes in water quality in the rainy season. The entry of fertilizer, domestic, and fish cultivation feed waste causes an increase in the concentration of TN, TP, BOD, COD, and DO in Darma Reservoir water.

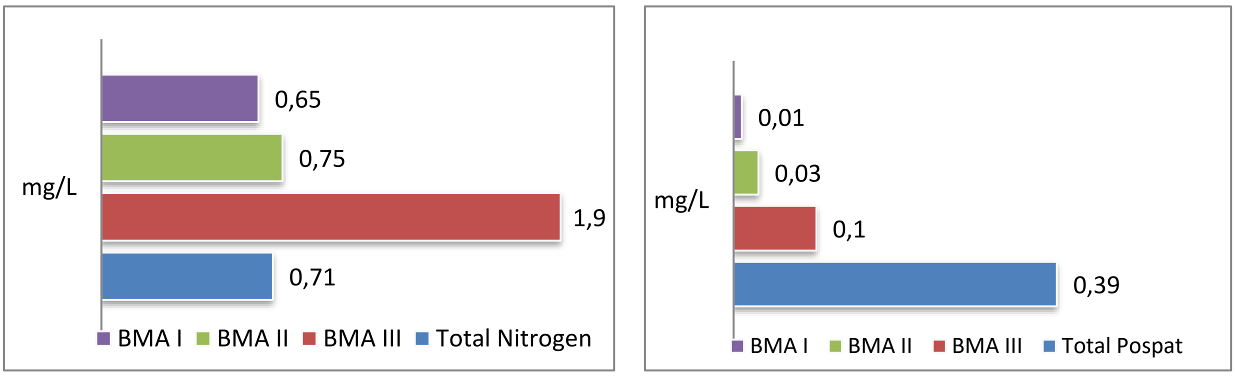
3.2. Dry Season Water Quality

The dry season in 2023 will last for 6 months, starting from June to November. Based on the results of the physical parameter test, the average water temperature of the Darma Reservoir is 27.75 0 C with a concentration of dissolved particles (TDS) of 76.67 mg/L and suspended particles of 94.08 mg/L. The complete results of the physical, chemical, and biological parameter tests are presented in **Table 7.** TDS, TSS, and water temperature concentration for the physical parameter group still follow the BMA standard. The pH concentration in the dry season still follows the water quality standard, while the concentration of other chemical parameters increases. The concentration of chemical parameters consisting of TN, TP, BOD, COD, and DO show different values for the classification of water utilization according to the BMA as stipulated in Government Regulation Number 22 of 2021. The concentration of TN in the dry season does not meet the Class I quality standard if used as raw water for drinking water. The concentration of TP in the water of Darma Reservoir does not meet the BMA standard for class I, II, and III utilization classes, while there is no limit for class IV. The BOD concentration value in the water shows conditions that do not meet the standards for class I and II water utilization classes. The COD indicates the same condition and DO concentrations, where both do not meet the BMA standard for class I utilization, while for classes II, III, and IV, they show suitability.

Table 7. Darma Reservoir Water Quality in the Dry Season

No.	Parameter	Unit	Test Value	Water Quality Classification (PP-22-2021)			
				I	II	III	IV
	Physics:						
1	Temperature	mg/L	27.04	Dev 3	Dev 3	Dev 3	Dev 3
2	TDS	mg/L	57.19	1,000	1,000	1,000	1,000
3	TSS	mg/L	13.86	25	50	100	400
	Chemistry:						
4	pH		7.44	6-9	6-9	6-9	6-9
5	Total Nitrogen	mg/L	0.71	0.65	0.75	1.9	-
6	Total Phosphate	mg/L	0.39	0.01	0.03	0.1	-
7	BOD	mg/L	3.68	2	3	6	12
8	COD	mg/L	10.76	10	25	40	80
9	DO	mg/L	5.94	6	4	3	1
	Biology:						
10	Total Coliform	CFU/100 ml	848.33	1,000	5,000	10,000	10,000
	Total STORET Index Score			-86	-32	-12	0
	Water Quality Status			Heavily Polluted	Heavily Polluted	Moderately Polluted	Meet Quality Standards

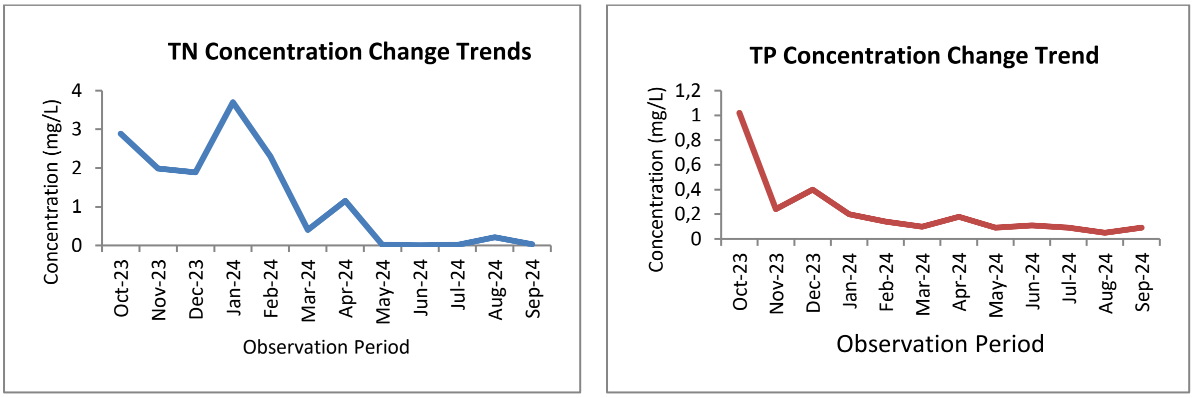
In the dry season, the flow of water supplying the Darma Reservoir affects the volume of water and the concentration of dissolved substances, thus affecting the water quality. Changes in weather in tropical areas, from the rainy to the dry season or vice versa, affect the quality of reservoir water (36). The dry season affects the quality of reservoir water's physical, chemical, and biological parameters (37). The water quality of the Darma Reservoir during the dry season is controlled by low rainfall and KJA cultivation. The high concentration of TN and TP (**Figure 4)** is the impact of intensive fish feeding to increase the harvest (38). KJA in the Darma Reservoir has exceeded the set limit of 1% of the reservoir area; the same condition is experienced in the Cirata Reservoir, which results in DO concentrations that do not meet BMA standards and high nutrient concentrations in the sediment (8). During the dry season, anthropogenic activities in the Darma Reservoir play an important role in the dynamics of reservoir water quality. Low solar radiation, rainfall, and KJA cultivation increase the concentration of TN and TP in reservoir water.



(a) **(b)**

Figure 4: (a) TN Concentration in the Dry Season; **(b)** TP Concentration in the Dry Season

Rainfall during the rainy and dry seasons can influence the pattern of water quality changes. **Figure 5** presents the trend of changes in TN and TP concentrations**.**



(a) **(b)**

Figure 5: **(a)** Trend of Changes in TN Concentration; **(b)** Trend of Changes in TP Concentration

Rain began to fall in November 2023, the rainy season began in December 2023 (**Table 5**), and the community began cultivating agricultural land. Agricultural activities in the upstream and along the *inlet river flow* with various crops, such as rice, corn, peanuts, and sweet potatoes are types that are commonly cultivated. Agricultural activities are also carried out in the reservoir boundary area that is not flooded during the dry season. The concentration of TN increased in January 2024 along with high rainfall (447.5 mm/month), and the area of reservoir water inundation 97% inundated the reservoir (**Table 5).** TP, although not experiencing a significant increase, was above BMA concentration. Nitrogen and Phosphorus are essential macronutrients that support the biological growth of cultivated plants (39). However, using intensive chemical fertilizers to increase food productivity can cause problems with water quality (40) in the form of increased concentrations of nitrate, phosphate, and urea (Pratama & Chamid, 2021). The concentration of TN and TP began to decrease along with the peak rainfall in March 2024, with water inundation reaching 96% of the inundation area. The increase in the area of reservoir water inundation is one factor that reduces the concentration of TN and TP, in addition to other environmental factors that were not studied.

3.3. Trophic Status

The concentration of TN and TP of Darma Reservoir water in the rainy and dry seasons were 3.52 mg/L, 0.2 mg/L, 0.71 mg/L, and 0.39 mg/L. The average concentration of TN and TP in the rainy and dry seasons were 2.12 mg/L and 0.295 mg/L. The average clarity of the reservoir waters was 0.78 m. Based on the criteria for determining the trophic status of lakes and/or reservoirs as stipulated in Regulation of the Minister of State for the Environment Number 28 of 2009 (**Table 4)**, the trophic status of the Darma Reservoir waters is *Hypereutrophic*. The increase in population encourages increased agricultural activities, industrialization, and urbanization, which have an impact on the eutrophication of freshwaters (42).

3.4. Ecological Risks

The real impact of increasing the fertility of Darma Reservoir waters to reach *Hypereutrophic* is *the blooming of* water hyacinth (*Eichornia crassipes* (Mart) Solms.). The concentration of TN and TP, which far exceeds BMA, results in a large amount of water hyacinth growth (*Eichornia crassipes) and a fish death disaster (* **Figure 6)**. Excessive water hyacinth growth as a response to increasing limiting factors such as sunlight, carbon dioxide, and nutrients needed in the photosynthesis process that drives the rate of eutrophication (43) is a natural process driven by anthropogenic activities (44).

(a) **(b)**

Figure 6: (a) *Blooming* water hyacinth; **(b)** mass death of fish

During the day, water hyacinth produces oxygen. Aquatic organisms only breathe at night, releasing CO_2, lowering the pH, and consuming O_2 simultaneously (45). DO water at night becomes lower so that it has the potential for large-scale fish deaths (46). The uncontrolled growth of water hyacinth in the Darma reservoir has hampered the mobility of fishing boats and reduced the aesthetic value of tourist destinations. Water hyacinth has attacked many tropical and subtropical countries, disrupting power plants, irrigation, navigation, fishing, and as a habitat for malaria mosquitoes (47). Mitigating the risk of ecological disasters in the Darma Reservoir is necessary through various efforts to improve water quality. Previous research shows that efforts to prevent eutrophication effectively with appropriate technology have not been able to be carried out, so more innovative and sustainable research is needed (42).

4. Conclusion and Recommendations

The air quality at the research location is heavily polluted during the rainy and dry seasons. The high concentration of TN and TP at the research location is caused by runoff from agricultural areas, feeding of fish cultivated in floating net cages, and disposal of domestic waste that has not been correctly processed. Anthropogenic activities at the research location encourage the rate of eutrophication to reach hypereutrophication, which causes economic losses and causes ecological disasters. The government, through management institutions, needs to review policies and think about reservoir use. This research needs to be continued with innovative research to compare the quality of reservoirs sustainably and analyze the most effective water hyacinth biomass in improving reservoir quality to obtain appropriate methods for environmentally friendly and sustainable reservoir management.

Thank-you note

Thanks are conveyed to the Cimanuk-Cisanggarung River Basin Center for permitting research in the Darma Reservoir. Sucofindo Environmental Laboratory Cirebon-Indonesia is responsible for helping analyze water quality. The Indonesian Center for Biodiversity and Biotechnology (ICBB) Laboratory in Bogor -Indonesia, for helping analyze the Total Nitrate and Total Phosphate content in the roots, leaf stalks, and water hyacinth leaves. All parties who have helped complete this research. The Ministry of Education, Culture, Research and Technology of the Republic of Indonesia for funding the research with the master contract number 180/E5/PG.02.00.PL/2023.

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