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The use of phytoplankton communities for assessment of water quality in the Wadaslintang Reservoir in Indonesia

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Abstract

The use of phytoplankton as an indicator of water pollution is a promising tool for assessment of water quality. The purpose of this study was to determine whether diversity indices, including the species richness and diversity of phytoplankton, could be used for reliable assessment of water quality in the Wadaslintang Reservoir in Indonesia. Surveys were conducted monthly at eight sites, from July 2019 to October 2019. Phytoplankton was collected during the day at 10:00 until approximately 15:00 in the euphotic zone. The parameters investigated were species richness and the abundance of phytoplankton, as well as water quality parameters listed in Government Regulation Number 82 of 2001. The level of pollution was represented biologically by the Shannon–Wiener diversity index and physicochemically by the STORET (storage and retrieval of water quality data) index. Moreover, the two indices were compared to determine whether a particular diversity index was more effective for assessment of this reservoir. The results showed that during the dry season, 22 taxa of phytoplankton were present, belonging to Cyanophyta, Chlorophyta, Chrysophyta and Euglenophyta. During the wet season, 29 taxa were found, belonging to Cyanophyta, Chlorophyta, and Chrysophyta. Based on the Shannon-Wiener index and STORET index, water quality was better during the wet season than during the dry season. The results of water quality assessment using both indices were consistent, but the diversity index was a more sensitive indicator of pollution levels. Therefore, the Shannon–Wiener index is a useful tool for assessment of water quality in the Wadaslintang Reservoir.

Key words: *algae, pollution level, Shannon–Wiener index, STORET index, water quality*

INTRODUCTION

The Wadaslintang Reservoir was built primarily for the supply of irrigation water to 33,279 ha of surrounding paddy fields. Other benefits include electric power generation (more than 92 mlon kWh·y^{-1}), flood control, tourism, industrial water usage, and fisheries activities. Various activities around the reservoir have the potential to release waste into the reservoir, which can lead to increased levels of organic matter that damage water quality. A high level of organic matter will affect the nutrient level of the water, which impacts the size of the algal population. These problems are often the primary driver of water quality problems, such as eutrophication. Eutrophication occurs as a result of a marked reduction in water quality due to accumulation of nutrients, thereby causing explosive growth of algal or phytoplankton populations that exceed the carrying capacity of the reservoir.

Phytoplankton play important roles as primary producers in aquatic environments and are very sensitive to their physical environment [YANTI 2017]. Changes in the environment can cause changes in the phytoplankton community in terms of species presence, abundance, diversity, and dominance in their habitats [KOSTRYUKOVA *et al.* 2018]. Thus, observing phytoplankton populations can be a reliable tool for assessing the pollution status of water bodies in biomonitoring studies [PARMAR *et al.* 2016; SINGH *et al.* 2013]. Phytoplankton fulfill the requirements of an appropriate indicator, mainly due to their simple structure and function, and thus can be used to investigate quantitative changes in water quality over large geographical areas [PARMAR *et al.* 2016]. As such, the importance of algal dynamics – especially their response to environmental changes and nutrient fluctuations – has been noted by previous researchers. Sensitive species typically disappear from polluted environments, while tolerant species survive well. Notably, more than a thousand species of algae have been found to tolerate pollution. Thus, identification of organisms in various water systems can indicate relative pollution levels. The presence of phytoplankton can be used as an indicator of water pollution, in combination with chemical and physical indicators. As aquatic organisms, phytoplankton have many advantages as a biological benchmark of the level of ecological instability, as well as for evaluation of various forms of pollution. Changes in water quality can be identified from the abundance and composition of phytoplankton, as well as their diversity. Pollution can change the structure of an ecosystem and reduce the number of species in a community, leading to a decline in diversity.

The diversity of organisms at the genetic, species, and community levels can determine the adaptability of a population, which affects species interactions. Diversity comprises species richness and evenness. Species richness is the total number of species, while evenness is the distribution of the abundance (number of individuals or biomass) of each species. A species diversity index combines species richness and evenness into a single value. The most widely used index for assessment of species diversity is the Shannon–Wiener index (H'). A greater value of H' indicates greater species diversity. Greater diversity in an area indicates a more stable community in the region.

Human industrial and domestic activities (e.g., aquaculture using floating nets), have a negative impact on water quality, which can cause changes in the aquatic biological community. Therefore, the biological community structure can reflect changes in water conditions and the level of pollution [LIWUTANG *et al.* 2013]. Efforts to control water pollution through management policies require monitoring of water quality.

This monitoring is generally performed using physical or chemical parameters. Recently, biota monitoring has gained attention, given that the biological community is more responsive to poor water quality, as organisms are directly affected by water over a long period; in contrast, physical and chemical properties tend to indicate water quality only at the time of measurement. In addition, biological sampling is environmentally friendly, inexpensive, rapid, and easy to interpret; therefore, phytoplankton have become a promising tool for water quality monitoring, providing early warning signs of pollution [SINGH *et al.* 2013]. Pollution can change the structure of an ecosystem and reduce the number of species in a community, causing decline in diversity. Thus, the diversity index of a polluted ecosystem is always smaller than the index of a natural ecosystem. Aquatic diversity is generally expressed in terms of the number of species present: a greater number of species is regarded as greater diversity. The relationship between the number of species and the number of individuals can be expressed in the form of a diversity index.

The influences of dry and wet season climates on water quality in the Wadaslintang Reservoir are strong. During the dry season, rivers entering the reservoir have reduced flow volume; the quality of water in the reservoir is determined by the quality of river water entering the reservoir. River water flowing into the reservoir will provide dissolved oxygen and nutrients into the body of water. Based on the findings in PIRANTI *et al.* [2018a], the total nutrient inputs (TN and TP) are higher in the wet season than in the dry season. Based on the results of correlation analysis between nutrient input (TN and TP) and reservoir inflow discharge, there are very strong positive associations between the level of nutrient input and both TP and TN. Reservoir operation is highly dependent on river flow into the reservoir, and further affects water quality conditions in the reservoir [NASCIMENTO DO VASCO *et al.* 2019]. Nutrients input as fish food accumulate at the bottom of the reservoir and can be resuspended into the water column. During the wet season, river water discharge increases, allowing the reservoir to be used for hydropower generation, which affects the aquatic ecosystem. These differing seasonal dynamics are readily apparent; changes in the structure of the phytoplankton community, representing the primary producers in the Wadaslintang Reservoir, reflect changes in water conditions and pollution levels.

Based on these factors, the present study aimed to determine whether diversity indices, including the species richness and diversity index of phytoplankton, can serve as practical tools for assessment of the water quality of a reservoir with seasonal changes.

MATERIALS AND METHODS

STUDY AREA

The Wadaslintang Reservoir is a constructed reservoir located in the Wadaslintang District, Wonosobo Regency, Central Java, Indonesia. The Wadaslintang Reservoir is located between 7°26'33" S and 7°36'40" S and 109°47'07" E and 109°51'19" E, with a total area of 19,198.05 ha. The water sources for the Wadaslintang Reservoir are rainwater that enters through rivers and rainfall directly into the reservoir. The main water sources for the reservoir are the Medono River, Gede River, and Bedegolan River, along with several other small tributaries; these combine to supply water to the reservoir at a mean rate of 15 $m^3 \cdot s^{-1}$. The reservoir area is 14.6 km^2, with a maximum water volume of 527 mln m^3, maximum elevation of 190.3 m a.s.l., and mean depth in the lacustrine area of 28.4 m [BBWSO 2015].

Human activity in water catchments has a strong influence on reservoir water quality, particularly in terms of the disposal of local household waste into rivers that flow into reservoirs. Likewise, agricultural activities in water catchments that employ fertilizers, both organic and inorganic, can increase the phosphate (P) and nitrogen (N) contents of reservoir waters. Human activities in reservoir areas that cause water quality degradation include fish farming activities using floating net cages, which are carried out by the local community and PT Aquafarm. Feeding of these fish allows some pellets that are not consumed to contribute to the level of pollution in the reservoir.

STUDY METHODS

This study was conducted using a survey method at eight sites in the Wadaslintang Reservoir, during both the dry and wet seasons. The sites represented the entire reservoir ecosystem, with a range of environmental conditions including riverine, transitional, and lacustrine zones. There were three inlet sites, one site in the transitional area, two sites in fish cultivation areas with floating nets managed by the local community and PT Aquafarm, and two sites in the deepest zone including the outlet (hydropower intake). The locations of sampling sites in the Wadaslintang Reservoir are presented in Figure 1.

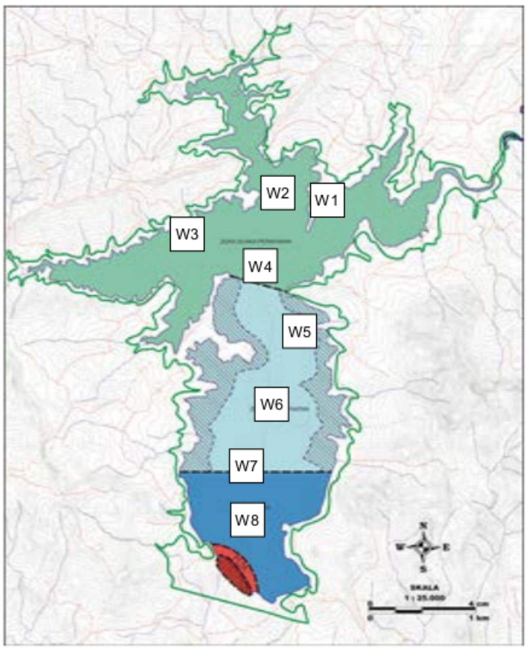

Fig. 1. Sampling sites (W1–W8) in the Wadaslintang Reservoir; source: own elaboration

In this study, water samples were collected with a 2 dm^3 van Dorn bottle monthly from July 2019 to October 2019 in the euphotic zone (approximately 0.3–0.5 m below the surface) at each site. Phytoplankton sampling was performed during the day at 10.00 AM, until approximately 03.00 PM. Up to 100 dm^3 of water were poured into a phytoplankton net for filtration, transferred to sample vials with 2–3 drops each of 4% formalin and Lugol's solution, and then sealed tightly to prevent spilling. An additional 2 dm^3 of water were collected in a 2-dm^3 sample bottle for measurement of chemical parameters. The parameters observed included the species richness and abundance of phytoplankton, as well as the water quality parameters listed in the Government Regulation of Indonesia Number 82/2001 (i.e., Water quality management and water pollution control).

The results of phytoplankton identification in the laboratory were used to determine the diversity of phytoplankton in the Wadaslintang Reservoir, based on the Shannon–Wiener index. Index calculations were conducted using the PASS program. To determine whether phytoplankton diversity was high or low, and to assess the level of water pollution in the Wadaslintang Reservoir, phytoplankton diversity index values were analyzed descriptively based on criteria for phytoplankton diversity [ODUM 1971]. If the Shannon–Wiener index (*ID*) is <2.3026 mean that phytoplankton is in low diversity, low distribution of individuals in each species, if the range of 2.3026–6.9076 means that it is moderate diversity, moderate distribution of individuals in each species, whereas if it is >6.9076 means high diversity, high distribution of individuals in each species.

Data for phytoplankton species richness and abundance were collected to determine the Shannon–Wiener diversity index and then analysed descriptively by comparison with the pollution level criteria presented by LEE *et al.* [1978] respectively as follows: unpolluted (*ID* > 2.0), light pollution (1.6–2.0), moderate pollution (1.0–1.5), and heavy pollution (<1.0).

To determine the water quality status of Wadaslintang Reservoir based on physical and chemical factors during observation, physical and chemical parameters were analyzed using the STORET method [ESTA *et al.* 2016] to identify the STORET index that represented the water quality status. This method included determination of the minimum, maximum, and mean values based on four measurements over four months, which are used as the basis for calculation. The index thus obtained can be used to further classify the water quality into four classes, namely:
1) class A: very good, score = 0, meets the quality standard (unpolluted);
2) class B: good, score from –10 to –1 mildly polluted;
3) class C: moderate, score from –30 to –11, moderately polluted;
4) class D: poor, score: <–31, heavily polluted.

Determination of the score and water quality status using the STORET method is performed by means of the following steps:
1) comparison of the measured data for each water parameter with quality standard values corresponding to the water quality classes according to Government Regulation of the Republic of Indonesia Number 82 in 2001: Water quality management and water pollution control [Peraturan… 2001];
2) if the measurement results meet the quality standard value (measurement results < quality standard), a score (0) is assigned;
3) if the measurement results do not meet the water quality standard (measurement results > quality standard), a score is given based on the parameter group and number of samples, as shown in Table 1.

The suitability of phytoplankton for assessment of water quality in the Wadaslintang Reservoir was evaluated by comparing the water quality determined using physicochemical methods based on the STORET index and the water quality determined using the phytoplankton diversity index. If the results of those assessments were consistent, phytoplankton were judged to be suitable for use in water quality assessment and monitoring in the Wadaslintang Reservoir.

Table 1. System for determination of water quality status

Number of samples	Score for water quality parameter								
	physical			chemical			biological		
	max.	min.	avg	max.	min.	avg	max.	min.	avg
<10	–1	–1	–3	–2	–2	–6	–3	–3	–9
>10	–2	–2	–6	–4	–4	–12	–6	–6	–18

Source: ESTA *et al.* [2016], modified.

Table 2. Phytoplankton diversity and abundance during the dry season in Wadaslintang Reservoir

Species[1)]	Phytoplankton abundance (ind·dm^{-3}) at each sampling site							
	W1	W2	W3	W4	W5	W6	W7	W8
Cyanophyta								
Oscillatoria limosa	0	0	0	0	0	0	0	966
Lyngbya sp.	0	0	0	0	3	0	0	0
Chlorophyta								
Polyedrium trigonum	0	0	2	5	3	0	0	0
Polyedrium lobulatum	0	483	2	0	0	3	0	0
Pediastrum simplex	0	0	1	0	0	0	0	0
Staurastrum tetracerum	0	0	4	6	966	3	0	0
Zygnemopsis americana	483	966	0	0	3	0	1	0
Xanthidium sp.	0	0	4	0	3	0	0	483
Chrysophyta								
Navicula brachysira	0	0	3	0	0	0	0	0
Tabellaria flocculosa	483	2	2	0	483	5	0	0
Cyclotella sp.	8	12	14	104	16	8	966	2
Navicula platystoma	0	0	1	0	0	0	0	0
Navicula insuta	0	0	1	0	0	0	0	0
Synedra acus	0	13	5	4	9	5	4	2
Pinnularia tabellaria	0	966	966	0	483	483	0	0
Cymbella naviculiformis	0	0	2	0	0	2	0	0
Achnanthes coarctata	0	1	483	0	0	2	0	0
Surirella elegans	0	0	6	0	0	-	0	0
Surirella robusta	0	0	4	0	0	3	0	0
Surirella tenera	0	0	2	0	0	2	0	0
Rhopalodia gibba	0	0	0	0	483	0	0	0
Euglenophyta								
Euglena pseudoviridis	483	0	0	0	966	0	0	0
Total of abundance	**1457**	**2443**	**1502**	**115**	**3415**	**516**	**971**	**1453**
Number of taxa	4	6	17	4	11	10	3	4
Shannon–Wiener index	1.127	1.117	0.8518	1.324	1.606	0.3707	0.03484	0.6556
Level of diversity	low							
Level of pollution	moderate		heavy	moderate		heavy		

[1)] Species names acc. to GRAHAM *et al.* [2009].
Explanations: W1 = the Medono River, W2 = the Lancar River, W3 = the Kemejing River, W4 = transition zone, W5 = floating net of local community, W6 = floating net of PT Aquafarm, W7 = lacustrine zone, W8 = outlet area.
Source: own study.

RESULTS AND DISCUSSION

DRY SEASON

The community structure in Wadaslintang Reservoir during the dry season, including the diversity and abundance of phytoplankton, is presented in Table 2.

During the dry season, 22 phytoplankton species (Fig. 2) were observed, including 4 phytoplankton divisions of Cyanophyta (3 species), Chlorophyta (6 species), Chrysophyta (14 species), and Euglenophyta (1 species). The abundance of phytoplankton ranged from 115–2443 ind·dm^{-3} (Tab. 4). The most abundant phytoplankton were members of the Chrysophyta or Bacillariophyta division (58.3%), followed by Chlorophyta (25%), Cyanophyta (12.5%), and Euglenophyta (4.2%) (Fig. 2).

Bacillariophyta is a phytoplankton group that is resistant to organic pollutants; thus, organic pollutants are generally responsible for high abundances of Bacillariophyceae [RAGI *et al.* 2017]. Cyanophyceae are considered good indicators of eutrophication. During the dry season, the number of Cyanophyta increased. High levels of phosphate, nitrate, and sulfate favor high abundances of Cyanophyceae [DOLMAN *et al.* 2012]. Increased numbers of cyanobacteria and coccoid Chlorophyta are natural consequences of a slightly elevated trophic level [DEMBOWSKA *et al.* 2018]. A relatively high pH also causes an increased level of Bacillariophyta. KUMAR and OOMMEN

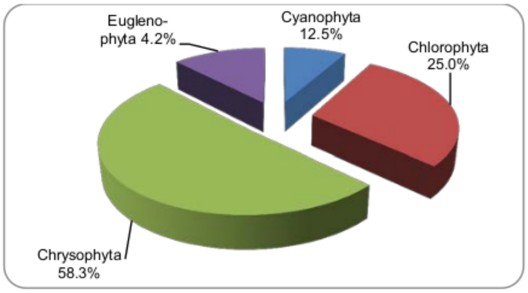

Fig. 2. Phytoplankton composition in Wadaslintang Reservoir during the dry season; source: own study

[2009] noted that waters with acidic pH do not support abundant Bacillariophyceae.

The magnitude of the phytoplankton diversity index during the dry season ranged from 0.03 to 1.6. Based on the criteria for pollution levels established by LEE *et al.* [1978], the waters of the Wadaslintang Reservoir were moderately to heavily polluted during the dry season (Tab. 1). Severely polluted conditions have been observed in the waters of the Kemejing River. These results are likely because the river passes through an inhabited area before entering the reservoir, which may increase domestic waste input. In the floating net area managed by the PT Aquafarm, the middle of the reservoir, and near the outlet, the reservoir is heavily polluted. This condition is presumably caused by fish feed residue and fish droppings that fall to the bottom of the reservoir, carrying high phosphorus that drives increases in certain types of phytoplankton able to tolerate high-phosphorus conditions. Based on the findings by PIRANTI *et al.* [2018b], the phosphorus load from floating net cages has exceeded approximately 50% of the reservoir's capacity.

WET SEASON

During the wet season, 29 phytoplankton species were observed, consisting of Cyanobacteria (3 species), Chrysophyta (15 species), and Chlorophyta (11 species) (Tab. 3).

Table 3. Phytoplankton diversity and pollution level during the wet season

Species[1)]	Phytoplankton abundance (ind·dm^{-3}) at each sampling site							
	W1	W2	W3	W4	W5	W6	W7	W8
Cyanobacteria								
Oscillatoria limosa	–	0	0	0	578	0	0	0
Merismopedia sp.	4,161	0	2,890	1,040	0	0	0	0
Lyngbya sp.	0	0	0	0	809	0	0	0
Chrysophyta/Bacillariophyta								
Achnanthes coarctata	0	809	0	2,080	0	3,236	0	578
Achnanthes lanceolata	2,774	1,734	0	4,623	0	0	0	2,658
Amphipleura	0	–	693	1,849	2,196	0	0	231
Treubaria sp.	5,201	578	3,699	2,080	2,427	3,121	3,121	925
Cymbella naviculiformis	0	0	578	0	1,618	0	0	347
Cyclotella sp.	809	347	578	231	116	578	231	578
Navicula brachysira	–	0	1,271	347	0	0	0	1,618
Navicula insuta	–	0	1,849	0	0	0	0	2,427
Navicula platystoma	–	0	809	925	0	0	0	578
Pinnularia tabellaria	–	925	0	0	578	0	0	0
Surirella elegans	–	0	462	0	0	0	0	1,387
Surirella robusta	116	0	925	0	231	0	0	2,658
Surirella tenera	0	0	347	0	0	0	0	0
Synedra acus	0	0	231	0	578	0	0	925
Tetraedon sp.	116	0	0	–	0	0	0	0
Chlorophyta								
Coelastrum sp.	10,402	1,965	925	2,196	0	0	0	0
Treubaria triappendiculata	116	0	0	0	0	578	1,040	116
Closterium porrectum	462	0	0	0	0	0	0	0
Pediastrum simplex	2,774	578	0	0	0	462	0	0
Pediastrum tetras	231	2,080	0	0	0	0	925	1,618
Rhopalodia gibba	347	578	578	0	0	1,387	0	578
Scenedesmus quadricauda	13,985	0	3,467	925	0	2,890	0	0
Euastrum sp.	3,005	0	462	0	0	0	0	0
Staurastrum dejectum	1,040	0	462	2,196	231	1,387	0	0
Staurastrum tetracerum	3,583	0	809	3,121	809	1,040	0	347
Microspora sp.	4,623	0	0	2,196	0	0	0	0
Total of abundance	53,745	9,593	21,036	23,809	10,171	14,679	5,317	17,568
Number of taxa	17	9	18	13	11	9	4	16
Shannon–Wiener index	2,227	2,027	2,562	2,364	2,080	1,979	1,072	2,489
Level of diversity	moderate					low		moderate
Level of pollution	none	none	none	none	none	light	moderate	none

[1)] Species names acc. to GRAHAM *et al.* [2009]. Explanations: W1–W8 as in Table 2. Source: own study.

Phytoplankton abundances in the wet season at all observation sites ranged from 5.317 to 53.745 ind·dm^{-3}. The diversity index ranged from 1.07 to 2.56, indicating that the Wadaslintang Reservoir was unpolluted during the wet season at most sampling locations; notably, the area of floating net cage cultivation managed by the local community (W6) was mildly polluted, while the PT Aquafarm floating net site (W7) was moderately polluted (Tab. 3). The unpolluted condition was caused by extensive water discharge, which led to pollutant dilution. In the floating net area managed by the local community, the level of pollution was lower than in the area of the PT Aquafarm floating nets; waste production from the community net area (39.2 t·y^{-1}) was less than the waste production from the PT Aquafarm facility (177.3 t·y^{-1}) [PIRANTI *et al.* 2018b].

The composition of phytoplankton during the wet season is presented in Figure 3. Of the 29 species observed, Chlorophyta comprised 52%, Cyanophyta comprised 3%, and Chrysophyta comprised 45%. Chlorophyta were more abundant during the wet season than during the dry season. The abundance of Chlorophyta was supported by high nutrient levels and alkaline pH, whereas nutrient pollution that caused increased levels of mineralized products led to lower levels of Chlorophyta [DARRIS, VINOBABA 2012]. High dissolved oxygen concentrations also have been positively associated with the growth of Chlorophyceae [KHANDAY, KHANDAY 2018]. Therefore, during the wet season, the number of Chlorophyta increased (52%) – Figure 3.

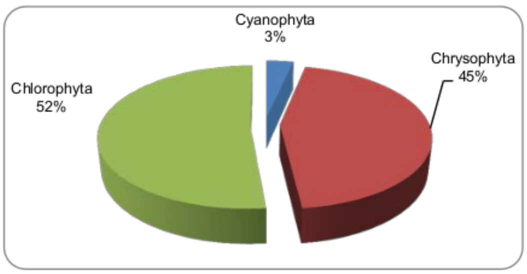

Fig. 3. Phytoplankton composition in Wadaslintang Reservoir during the wet season; source: own study

COMPARISON OF PHYTOPLANKTON STRUCTURE DURING THE DRY AND WET SEASONS

The structure of the phytoplankton community in the Wadaslintang Reservoir differed between the dry and wet seasons (Tab. 4). Community structure is a concept that includes species composition or species richness, as well as species abundance in the community.

As shown in Table 3, the mean abundance of phytoplankton was lower in the dry season (11.879 ind·dm^{-3}) than in the wet season (40.342 ind·dm^{-3}). Factors that can cause low phytoplankton abundance include season [ETISA *et al.* 2018]. During the wet season, the concentration of nutrients is lower than the concentration during the dry season; therefore, phytoplankton density is also low. This condition is due to high rainfall during the wet season, which leads to low light penetration, low temperature, and high turbidity, compared to the dry season.

Table 4. Seasonal phytoplankton structure in Wadaslintang Reservoir

Parameter	Dry season	Wet season
Abundance (ind·dm^{-3})	11.879	40.342
Species richness (%)	Cyanobacteria (12.5%)	Cyanobacteria (3%)
	Chlorophyta (25%)	Chlorophyta (52%)
	Chrysophyta (58.3%)	Chrysophyta (45%)
	Euglenophyta (4.2%)	–
Shannon–Wiener index	0.89	2.10
Pollution level	highly polluted	unpolluted

Source: own study.

The number of taxa changed markedly between seasons. During the wet season, 29 taxa were present, comprising Cyanobacteria (3%), Chlorophyta (52%), and Chrysophyta (45%); in the dry season, 22 taxa were present, comprising Cyanobacteria (12%), Chlorophyta (25%), Chrysophyta (58%), and Euglenophyta (4%). The abundance of Cyanophyta increased abruptly during the dry season (4% during the wet season, compared to 12% during the dry season). Euglenophyta were only recorded during the dry season, indicating the presence of organic or inorganic contaminants in the Wadaslintang Reservoir.

The value of the Shannon–Wiener index depends on the number of individuals of the phytoplankton species observed. If several phytoplankton species are present with large numbers of individuals such that the total number of individuals is proportional to the number of individuals of each species, the diversity value is higher. Analysis indicated that the value of the Shannon–Wiener index was higher in the wet season than in the dry season (Fig. 4). This result indicates that water quality is better during the wet season than during the dry season.

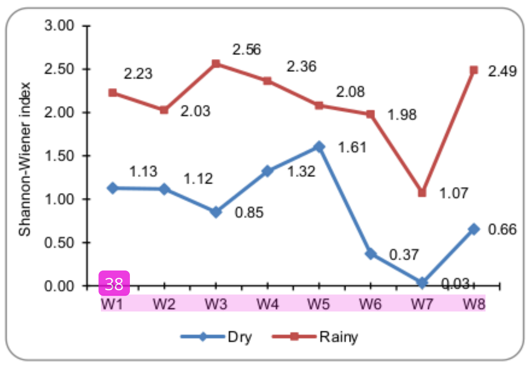

Fig. 4. Seasonal comparison of Shannon–Wiener index values; W1–W8 as in Table 2; source: own study

SEASONAL COMPARISON OF WATER QUALITY BASED ON PHYSICOCHEMICAL MEASUREMENTS

Based on monitoring of water quality using physicochemical parameters that have been previously reported [PIRANTI *et al.* 2019], the water quality status of Wadaslintang Reservoir was heavily polluted during the dry season, whereas it was moderately polluted during the wet season. The number of parameters that were above the standard was greater in the dry season (10 parameters) than in the wet season (3 parameters) – Table 5. The 10 parameters that exceeded the standard in the dry season were total suspended solids (*TSS*), biological oxygen demand (*BOD*), chemical oxygen demand (*COD*), orthophosphate, cadmium (Cd), copper, lead (Pb), hydrogen sulphide (H_2S), oils and lipids, and detergents (Tab. 5). During the dry season, only 3 parameters (*TSS*, *BOD*, and H_2S) exceeded the standard.

TSS are suspended materials >1 μm diameter that can be collected using a Millipore filter with a pore diameter of 0.45 μm. Physically, *TSS* contribute to turbidity in water. The presence of excess *TSS* in water can disrupt the activities of aquatic organisms. WISHA *et al.* [2016] noted that the correlation between *TSS* and phytoplankton exhibited inverse proportionality: when the *TSS* concentration was reduced, the abundance of phytoplankton increased. This result indicated that the relationship between *TSS* and concentration phytoplankton is strong; because phytoplankton require sunlight to perform photosynthesis, turbid water hampers the process of photosynthesis, thereby inhibiting phytoplankton growth.

Table 5. Physicochemical water quality parameters above the regulatory standard by season

Parameter	Concentration ($mg \cdot dm^{-3}$)		Limit acc. to class II [Peraturan… 2001]
	dry season	wet season	
TSS	235.2[1)]	153.1[1)]	50.0
BOD	6.2[1)]	4.7[1)]	3.0
COD	30.9[1)]	24.0	25.0
Orthophosphate	0.49[1)]	0.14	0.2
Cadmium	0.015[1)]	0.009	0.01
Copper	0.016[1)]	0.008	0.02
Lead	0.027[1)]	0.024	0.03
H_2S	0.010[1)]	0.009[1)]	0.002
Oils and fats	1,106.1[1)]	385.6	1000
Detergent	250.9[1)]	130.0	200.0

[1)] Above class II water quality standard of Indonesian [Peraturan… 2001].
Source: own study.

Chemical oxygen demand (*COD*) and biological oxygen demand (*BOD*) are measures of the amount of organic matter present in water. Water with high *COD* or *BOD* values is polluted with organic matter [HORNE, GOLDMANN 1994]. Furthermore, orthophosphate is a form of dissolved phosphorus, which is a key element required for plant growth in lake ecosystems, as it tends to be the limiting nutrient. Its presence drives eutrophication, characterized by excess growth of algae and plants in aquatic ecosystems [HORNE, GOLDMANN 1994]. During the dry season, the orthophosphate concentration was 0.34 $mg \cdot dm^{-3}$, which exceeded the class II water quality standard of 0.2 $mg \cdot dm^{-3}$ (Tab. 5).

The presence of heavy metals in aquatic environments can negatively influence organisms from the individual level to the community level. The main sources of high concentrations of Cd and Pb in water are human activities such as mining, household waste disposal, the waste disposal industry, and the flow of agricultural waste into aquatic environments. The high Pb and Cd levels in the Wadaslintang Reservoir are caused by human activities in the catchment area; in particular, rice fields that use large amounts of agricultural fertilizer are the main sources of Pb and Cd.

H_2S is a foul-smelling gas produced from the decomposition of sulphur compounds in organic material by anaerobic bacteria, which occur only in polluted waters that lack dissolved oxygen. When dissolved oxygen is unavailable, the decomposition of organic matter is performed by anaerobic microorganisms that emit H_2S and methane gas [PURNOMO *et al.* 2013]. During the wet season, H_2S did not exceed the quality standard of 0.002 $mg \cdot dm^{-3}$; during the dry season, the concentration of H_2S was very high (0.01 $mg \cdot dm^{-3}$). This result indicated that during the dry season in the Wadaslintang Reservoir, organic material undergoes anaerobic degradation, presumably due to the accumulation of faeces and unconsumed fish feed [PIRANTI *et al.* 2018b].

Oil and fat pollution can float on the surface of the water and can originate from various sources, including wastewater released by households, industry, and other sources in the local community. Oil does not dissolve in water; therefore, when water is polluted by oil, the oil remains on the surface. Water pollution with oil is exceedingly detrimental to the aquatic ecosystem because it can reduce the penetration of light into the water and can reduce the concentration of dissolved oxygen by inhibiting the uptake of oxygen through the water surface. These reductions in light penetration and oxygen due to the presence of oil can disrupt algal communities.

Detergent is an effective cleaning agent that is used for various purposes by both households and industry. Detergent soap is made from natural ingredients including fat, fatty acids, and caustic soda, which allow it to dissolve in water; these ingredients also bind fat to remove it from the object undergoing cleaning. The high level of detergent in the Wadaslintang Reservoir is a result of domestic activities that result in direct waste disposal into rivers, which then flow into the reservoir.

COMPARISON OF SEASONALITY IN BIOLOGICAL AND PHYSICOCHEMICAL ASSESSMENTS

Comparison of water quality assessment results for the pollution level of Wadaslintang Reservoir, based on the diversity index and physical chemistry, revealed similar findings. During the dry season, physicochemical measurements of water quality status at all stations in the reservoir showed a heavily polluted status (Tab. 6). However, phytoplankton monitoring indicated that some sites were heavily polluted (W3, W6, W7, W8), although other sites were only moderately polluted. This result indicates that biological assessment is more sensitive and better describes actual conditions. Site W3 was heavily polluted because it was located in the reservoir inlet area of the Kemejing River; notably, the Kemejing River passes through residential areas where domestic waste disposal activities have a strong impact. Site W6 was a fish culture area that contained floating nets managed by PT Indonesia Power, which uses a super-intensive feeding system that likely causes large amounts of leftover food to pollute the area. Sites W7 and W8 were located in the lacustrine zone;

Table 6. Comparison of water quality biological and physicochemical assessments during the dry season

Code	Site	Biological assessment		Physicochemical assessment	
		diversity index	water quality status acc. to LEE *et al.* [1978]	STORET index	water quality status acc. to Peraturan… [2001]
W1	the Medono River	1.127	moderately polluted	–120	heavily polluted
W2	the Lancar River	1.117	moderately polluted	–120	heavily polluted
W3	the Kemejing River	0.852	heavily polluted	–136	heavily polluted
W4	transition zone	1.324	moderately polluted	–120	heavily polluted
W5	floating net area belonging to traditional communities	1.606	moderately polluted	–104	heavily polluted
W6	floating net belonging to PT Aquafarm	0.371	heavily polluted	–104	heavily polluted
W7	lacustrine zone	0.034	heavily polluted	–120	heavily polluted
W8	outlet area	0.656	heavily polluted	–136	heavily polluted
Average		1.294	moderately polluted	–120	heavily polluted

Source: own study.

Table 7. Comparison of water quality biological and physicochemical assessments during the wet season

Code	Site	Biological assessment		Physical/chemical assessment	
		diversity index	water quality status acc. to LEE *et al.* [1978]	STORET index	water quality status acc. to Peraturan… [2001]
W1	the Medono River	2.227	unpolluted	–19	moderately polluted
W2	the Lancar River	2.027	unpolluted	–19	moderately polluted
W3	the Kemejing River	2.562	unpolluted	–19	moderately polluted
W4	transition zone	2.364	unpolluted	–19	moderately polluted
W5	floating net area belonging to local communities	2.080	unpolluted	–19	moderately polluted
W6	floating net area belonging to PT Aquafarm	1.979	moderately polluted	–19	moderately polluted
W7	lacustrine zone	1.072	moderately polluted	–19	moderately polluted
W8	outlet area	2.489	unpolluted	–19	moderately polluted
Average		2.103	unpolluted	–19	moderately polluted

Source: own study.

they were exposed to dry conditions for an extended duration in the dry season when hydropower generation was interrupted and the water supply into the reservoir was dramatically reduced. These conditions provided opportunities for phytoplankton to multiply with the support of nutrients supplied by fish culture activities.

The water quality conditions of the Wadaslintang Reservoir were generally better during the wet season than during the dry season. Based on physicochemical measurements, water quality throughout the observation area exhibited moderately polluted status (Tab. 7). The mean diversity index of phytoplankton was 2.1, indicating unpolluted water. Polluted conditions were found at only two sites, the fish culture area of PT Aquafarm and the lacustrine zone (Tab. 7).

These results indicate that physicochemical measurement can only describe the general pollution conditions; it cannot reflect the specific condition of the ecosystem. Biological measurements based on changes in the ecosystem respond quickly to changes experienced by organisms living in the area. This statement is supported by the findings of THAKUR *et al.* [2013], in that phytoplankton may act as biological indicators of pollution status. Phytoplankton diversity should be used rather than other methods for early detection of water quality changes, because of its low cost, rapid analysis, and ease of handling.

CONCLUSIONS

The water quality of the Wadaslintang Reservoir was worse during the dry season than during the wet season. The results of phytoplankton diversity index and STORET index analyses were generally consistent. The phytoplankton diversity index was higher during the wet season and more accurately reflected water quality. An association was observed between the diversity index and the STORET index for assessment of reservoir water quality. Notably, the diversity index was more sensitive to changes in water quality. Therefore, the phytoplankton diversity index could indicate the level of pollution, providing an accurate tool for assessment of water quality in the Wadaslintang Reservoir.

Monitoring the water quality of Wadaslintang Reservoir is better using biological parameters (phytoplankton) because it can monitor not just give a momentary overview but continuously and can provide early warning when contamination occurs.

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