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Research Article
Model of Phytoplankton Diversity in Belawan River, North Sumatera, Indonesia

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Abstract

Background and Objective: Belawan River is located in Deli Serdang and Medan Districts, North Sumatra, Indonesia. Belawan River passes through residential areas, industry, steam power plants (PLTU), PDAM and encroachment. Waste is directly discharged into water bodies due to many human activities, so the quality of water and aquatic biota is disturbed. Phytoplankton diversity is influenced by water quality conditions because its existence depends heavily on the water conditions of the Belawan River. Analyzing the model of phytoplankton diversity in the Belawan River was the purpose of this study. **Materials and Methods:** The analysis was conducted in the form of phytoplankton diversity by obtaining phytoplankton species and their distribution and analyze the environment such as the water quality of the Belawan River. Sampling was taken by purposive random method with 5 different locations with 3 times the test with, namely starting from the upstream, middle and downstream Belawan River area in 2010, 2015 and 2020. Stages of research methods, obtained types of plankton, abundance (A), relative abundance (RA), presence frequency (PF), equitability (E) and diversity (H) and analysis of water quality (temperature, light penetration, light intensity, depth, current speed, salinity, pH, DO, oxygen saturation percent, BOD and COD). **Results:** Twenty three genera of phytoplankton were found in 2020. Phytoplankton abundance was highest in the *Chaetoceros* sp., genera with an abundance of 186 ind m^{-2} at station 5. Diversity (H) was highest at station 5 at 2.30 and lowest at station 5 at 1.87. Phytoplankton in five stations was relatively low. The DO has a very strong effect on phytoplankton's diversity. The model of phytoplankton diversity relationship with water quality is $y = -2.09235475-0.283821248x_1-0.000034042331x_2^2-0.000000317192297x_3^2+0.0000138747473x_4^2-0.0642412267x_5^2+0.0436398590x_6-0.0107999363x_7^2+0.0000469016376x_8^2$. **Conclusion:** Dissolved oxygen (DO) has an effect on the diversity of phytoplankton in the Belawan River where the highest phytoplankton is *Chaetoceros* sp., of 23 genera which was found with a diversity value of 2.30 at station V.

Key words: Model, phytoplankton diversity, ecology, Belawan River, self-purification, environmental issues, steam power plants

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Belawan River is located in Deli Serdang and Medan Districts, North Sumatra, Indonesia. Belawan River has an area of 4,079 ha. Belawan River is located in two districts/cities, namely the Deli Serdang Regency covering an area of 3,802.93 ha (93.23%) and Medan City covering an area of 276.07 ha (6.77%)[1]. Belawan River crosses the Medan Area where the river flows through residential, industrial and steam power plants (PLTU), PDAM and encroachment[2].

Activities that occur around the Belawan River produce waste, thus increasing the pollutant load on the Belawan River waters. Waste discharged into rivers affects water quality and the diversity of phytoplankton, so, the function and structure of the river ecosystem are disrupted. If the load that enters a river exceeds the limit set based on environmental quality standards, then the river is considered polluted, both physically, with water quality (chemically) and phytoplankton (biologically).

The Belawan River with various activities carried out by the community around the Belawan River has the potential to increase the disposal of waste, both solid and liquid. If the polluted material that enters the river exceeds the limit set based on the quality standard, then the river is polluted, either chemically, physically or biologically, especially phytoplankton. It can be seen that the river is not able to carry out self-purification of the pollution load.

Water quality and phytoplankton diversity, affect ecosystem conditions, so this information is very important for water management purposes[3]. The effect of excessive activity is expected to cause changes in water quality which will then lead to pollution in river waters[4].

The problem of the Belawan River cannot be solved directly because of the complexity of the factors that influence it, therefore, modelling methods are used to simplify this complexity[5]. Policy implementation is still limited and there are still many problems that have not been studied. Therefore, it is essential to conduct this analytical study which is related to the impact of water quality on phytoplankton diversity in the Belawan River in the model form.

The management model with the highest priority is supervision and monitoring activities, which are part of river management and water pollution control. Water Quality Management and Water Pollution Control, according to PP RI No. 22 of 2021 article 2 paragraph (1) integrated ecosystem approach through water quality management and water pollution control. Furthermore, "it is stated that the integration referred to in paragraph (1) shall be carried out at the planning, implementation, monitoring and evaluation stages. Furthermore, it is stated that the integration referred to in paragraph (1) shall be carried out at the planning, implementation, monitoring and evaluation stages". One of the purposes of supervision was to check and find out the level of compliance of those in charge of activities and/or businesses with statutory provisions relating to environmental issues. For this reason, it is necessary to make efforts to formulate a management model for the phytoplankton diversity relationship with water quality in Belawan River.

MATERIALS AND METHODS

The research was carried out in 2020 plus 2015 and 2010 data. The impact of water quality on phytoplankton diversity in the Belawan River was conducted by sampling method using a purposive random sampling technique. Triplicate samples were collected from upstream to downstream of the river at each station with a total of 5 selected sampling stations. Side points on the Belawan River were taken based on community activities.

Water quality sampling: The parameters of water quality would be recorded using instruments as seen in Table 1.

Table 1: Measurement of Water quality

Water quality	Instrument	Place of measurement
Temperature (°C)	Thermometer	*In situ*
Light penetration (cm)	Secchi disk	*In situ*
Light intensity (Cd)	Lux meter	*In situ*
Flow rate (sec m^{-1})	Manual	*In situ*
pH	pH meter	*In situ*
DO (Dissolved oxygen)	Winkler method	*In situ*
BOD_5	Winkler and incubation method	Laboratory
COD	Reflux method	Laboratory

Phytoplankton collection: Phytoplankton communities were sampled five times using a plankton net and a 5 L bucket. The plankton net was submerged into the water of bottle film to rinse all the planktonic organisms until the water became concentrated. To preserve the samples, two drops of Lugol were added to the bottle film shortly afterward. Homogenized samples were observed under a microscope and identified using plankton identification books as referred to[6-9]. The measurement and analysis of phytoplankton abundance (A), relative abundance (RA), presence frequency (PF), equitability (E) and diversity (H) were then carried out to evaluate the current pollution level of Belawan River.

Data analysis: Abundance (A):

$$A = \frac{T}{L} \times \frac{P}{p} \times \frac{V}{v} \times \frac{1}{W}$$

With:

A = Abundance of plankton per liter
T = Surface area of counting chamber in the haemocytometer
L = Area of view
P = Number of enumerated plankers
p = Number of fields observed
V = Volume of plankton concentration in each bucket
v = Volume of plankton concentration under the cover glass
W = Volume of the sampled water filtered with a plankton net

Relative abundance (RA):

$$RA\ (\%) = \frac{n_i}{\sum N} \times 100$$

With:

RA = Relative abundance of plankton pe liter
n_i = The number of individuals from one species
ΣN = Total number of individuals from all species

Presence frequency (PF):

$$PF = \frac{\text{Number of plots occupied by a species}}{\text{Total number of plots}} \times 100$$

With:

PF = 0-25 (Rarely)
25-50 (Occasionally)
50-75 (Frequently)
>75 (Dominant)

Shannon-Wiener Diversity Index (H):

$$H' = \sum_{i=1} pi \ln pi$$

With:

H' = Shannon-Wiener diversity index
pi = ni/N (comparison of the number of individuals from one species to the total number of individuals)
ln = Natural algorithm

According to Krebs[10], "Diversity is classified as low if 0<(HI)<2.302, moderate if 2.302<(HI)<6.907 and high if (HI)>6.907".

Equitability index (E):

$$E = \frac{H'}{H_{Max}}$$

With:

E = Equitability Index
H' = Shannon-Wiener's diversity index
H_{max} = Maximum diversity index

According to Krebs[10], "The equitability value (E) ranges from 0 to 1, if the value is close to 1, it means high uniformity due to the absence of the dominating species. This means that the amount of individuals of the species is uniform and even".

Advanced multivariate analysis: All of the collected data such as temperature, pH, light intensity, light penetration, flow rate, DO, BOD_5 and COD were statistically analyzed to obtain their mean value. Phytoplankton diversity, equitability, presence frequency, relative abundance and abundance were calculated for comparison and prior analysis of any correlation with the physico-chemical parameter values. The diversity value (H') in waters was categorized to be heavily polluted if (H')<1, moderate if (HI) range between 1.0 and 1.5, while slightly polluted if (H')>2.0. Further analysis would be computed using SPSS Statistics ver. 22.

RESULTS AND DISCUSSION

Water quality of Belawan River: The mean value of physico-chemical parameters of water quality at each sampling station was shown in Table 2. Based on Table 2, water temperature in all five sampling stations ranges from 26-28°C, with its highest value recorded at stations II, IV and V. Apart from that, the fluctuation of the water temperature is relatively insignificant. In all stations, sunlight was able to penetrate a water surface about 43-69 cm below. The highest light penetration was obtained at station I because the area was well-lit and slightly overgrown with plants, which made the sunlight penetration more vulnerable into water bodies. As for light intensity which ranges from 534 to 1174 candela, where its highest value was recorded at station II, due to the high ability of light absorption. The pH range of water varies from 7.5-8.1, where the highest pH recorded at Station I which is the upstream area. In general, the pH is relatively the same. The results of water quality analysis showed a moderate relationship with phytoplankton[11].

The dissolved oxygen (DO) of the water body ranges from 5.10-6.87 mg L^{-1}. The highest value was recorded at station I, due to the sufficient environment which supported photosynthesis to run well, hence, it contributed a lot of oxygen in these waters. The mean value of dissolved oxygen in the Belawan River which is higher than 5 mg L^{-1}, is classified as a good water condition[12]. The summary from this research were DO, temperature and light intensity as physical factor of water had the highest correlation againts of biodiversity of phytoplanton[13]. The BOD_5 ranges from 22.50-42.50 mg L^{-1}, where the highest value is measured at station V in the estuary area, which is due to a lot of organic material, hence, oxygen is used a lot by microorganisms to break down organic material into simple molecules. The COD ranges from 56.50-92.50 mg L^{-1}, where the highest value is measured at stations I and V. The water qualities of the Belawan River, such as temperature, flow rate, light penetration and light intensity, have still undergone water quality standards. Meanwhile, pH, DO and BOD_5 has passed the water quality standard[14].

Abundance (A) (ind m^{-2}), relative abundance (RA) (%) and presence frequency (PF) (%) value of phytoplankton in Belawan River: The analysis results of phytoplankton abundance (A) (ind m^{-2}), relative abundance (RA) (%) and Presence frequency (PF) (%) values in Belawan River were shown in Table 3(a-b). It can be seen that the phytoplankton composition at station I consists of only 4 species, with the highest abundance of *Navicula* sp. The abundance, relative abundance and presence frequency values of *Navicula* sp., at station I was 37.2 ind m^{-2} (A), 42.86% (RA) and 66.66% (PF), respectively. At station II, 4 species were found, with the highest abundance of *Diatom* sp. The abundance, relative abundance and frequency of presence of *Diatom* sp., at station II were 37.2 ind m^{-2} (A), 33.33% (RA) and 100% (PF). At station III, 4 species were found, with the highest abundance of *Navicula* sp. The abundance, relative abundance and frequency of presence of *Navicula* sp., at station III were 62 ind m^{-2} (A), 8.47% (RA) and 66.66% (PF). *Navicula* is a genus of diatoms found in all research stations and has the highest abundance with abundance percentages ranging from 13.82-52.83% of the total abundance in the Babon River[15].

At station IV, the species with the highest value of abundance, relative abundance and frequency of presence values is *Navicula* sp., with 86.8 ind m^{-2} (A), 11.29% (RA) and 66.66% (PF), respectively. At station V, *Chaetoceros* sp., has the highest value of abundance, relative abundance and frequency of attendance, with records of 186 ind m^{-2} (A), 20% (RA) and 66.66% (PF). The high abundance of *Chaetoceros* sp., supported a lifelike, temperature of 26-30°C. The abundance of phytoplankton in the Belawan River ranges from 2612-17755 ind L^{-1} [16].

Value of diversity (H') and equitability index (E) in Belawan River: The value of diversity (H') and equitability index (E) at each sampling station in Belawan River in Table 4 showed that, the highest diversity value (H') is obtained at station V (2.30), whereas the lowest is at station I (1.28). This result also implied that the diversity of phytoplankton at all stations is classified

Table 2: Mean value of water quality parameters in Belawan River

Parameter	Station 1	Station 2	Station 3	Station 4	Station 5
Temperature (°C)	27	28	28	26	28
Light concentration (cm)	69	65	54	43	45
Light intensity (Cd)	921	1.174	865	534	744
Flow rate (sec/m)	9.5	70.5	12.4	37.6	13.6
pH	8.1	8.0	7.9	7.7	7.5
DO (mg/L)	6.87	5.92	5.10	5.48	4.48
BOD_5 (mg/L)	32.50	30.50	22.50	23.50	42.50
COD (mg/L)	92.50	81.50	83.50	56.50	92.50

Table 3A: Phytoplankton abundance (A) (ind m^{-2}), relative abundance (RA) (%) and presence frequency (PF) (%) value at Station 1 and 2 in Belawan River

	Station 1			Station 2		
Taxa	A	RA	PF	A	RA	PF
Chlorophyceae						
Scenedesmus sp.	-	-	-	12.4	11.11	33.33
Spirulina sp.	-	-	-	-	-	-
Netrium sp.	-	-	-	-	-	-
Ulothrix sp.	-	-	-	-	-	-
Radiofilum ap.	-	-	-	-	-	-
Closteriopsis sp.	-	-	-	-	-	-
Pediastrum sp.	-	-	-	-	-	-
Bacillariophyceae						
Diatom sp.	-	-	-	37.2	33.33	100
Cyclotella sp.	-	-	-	-	-	-
Amphiprora sp.	-	-	-	-	-	-
Bacillaria sp.	-	-	-	-	-	-
Achnanthes sp.	-	-	-	-	-	-
Chaetoceros sp.	-	-	-	-	-	-
Chrysophyceae						
Cymbella sp.	-	-	-	-	-	-
Surirella sp.	-	-	-	-	-	-
Cocconeis sp	-	-	-	-	-	-
Cyclotella sp.	-	-	-	-	-	-
Navicula sp.	37.2	42.86	66.66	37.2	33.33	66.66
Frustulia sp.	12.4	14.29	33.33	-	-	-
Nitzschia sp.	12.4	14.29	33.33	24.8	22.22	66.66
Gyrosigma sp.	-	-	-	-	-	-
Pinnularia sp.	24.8	28.57	33.33	-	-	-
Synedra sp.	-	-	-	-	-	-
Total	86.8	100.00		111.6	100.00	

Table 3B: Phytoplankton abundance (A) (ind m^{-2}), relative abundance (RA) (%) and presence frequency (PF) (%) value at Station 3, 4 and 5 in Belawan River

	Station 3			Station 4			Station 5		
Taka	A	RA	PF	A	RA	PF	A	RA	PF
Chlorophyceae									
Scenedesmus sp.	-	-	-	37.2	4.84	66.66	49.6	5.33	33.33
Spirulina sp.	12.4	1.69	33.33						
Netrium sp.	37.2	5.08	100	12.4	1.61	33.33	49.6	5.33	33.33
Ulothrix sp.	12.4	1.69	33.33	-	-	-	37.2	4	33.33
Radiofilum ap.	-	-	-	-	-	-	74.4	8	66.66
Closteriopsis sp.	12.4	1.69	33.33	-	-	-	-	-	-
Pediastrum sp.	24.8	3.39	66.66	-	-	-	-	-	-
Bacillariophyceae									
Diatom sp.	-	-	-	-	-	-			
Cyclotella sp.	-	-	-	-	-	-	12.4	1.33	33.33
Amphiprora sp.	-	-	-	12.4	1.61	33.33	-	-	-
Bacillaria sp.	-	-	-	-	-	-	24.8	2.67	33.33
Achnanthes sp.	-	-	-	-	-	-	12.4	1.33	33.33
Chaetoceros sp.	-	-	-	-	-	-	186	20	66.66
Chrysophyceae	-	-	-				-	-	-
Cymbella sp.	-	-	-	12.4	1.61	33.33	-	-	-
Surirella sp.	-	-	-	12.4	1.61	33.33	-	-	-
Cocconeis sp	24.8	3.39	33.33	-	-	-	-	-	-
Cyclotella sp.	37.2	5.08	33.33	-	-	-	-	-	-
Navicula sp.	62	8.47	66.66	86.8	11.29	66.66	49.6	5.33	66.66
Frustulia sp.	-	-	-	-	-	-	12.4	1.33	33.33
Nitzschia sp.	12.4	1.69	33.33	49.6	6.45	66.66	12.4	1.33	33.33
Gyrosigma sp.	-	-	-	24.8	3.23	33.33	62	6.67	66.66
Pinnularia sp.	-	-	-	24.8	3.23	66.66	24.8	2.67	66.66
Synedra sp.	-	-	-	-	-	-	124	13.33	33.33
Total	731.6	100		768.8	100		930	100	

Table 4: Phytoplankton diversity values (H') and equitability index (E) in Belawan River

Value	Station 1	Station 2	Station 3	Station 4	Station 5
H	1.28	1.31	2.03	1.93	2.30
E	0.92	0.94	0.92	0.88	0.87

Table 5: Correlation value obtained between the water quality parameters and phytoplankton diversity

Parameters	Diversity (H')
Temperature (°C)	0.519
Light concentration (cm)	-0.559
Light intensity (Cd)	-0.26
Flow rate (sec m^{-1})	-0.46
pH	-0.773
DO (mg L^{-1})	-0.837
BOD_5 (mg L^{-1})	0.619
COD (mg L^{-1})	0.427

Table 6: Correlation value between water quality parameters and phytoplankton diversity in 2010, 2015 and 2020

Parameters	2010 (H^l)	2015 (H^l)	2020 (H^l)
Temperature (°C)	0.984	0.32	0.519
Light concentration (cm)	0.801	-0.43	-0.559
Light intensity (Cd)	- 0.170	0.41	-0.26
Flow rate (sec m^{-1})	0.239	0.02	-0.46
pH	- 0.280	-0.31	-0.773
DO (mg L^{-1})	- 0.571	0.94	-0.837
BOD_5 (mg L^{-1})	- 0.120	0.52	0.619
COD (mg L^{-1})	0.760	0.75	0.427

as low. The value of phytoplankton diversity in the coastal waters of South Sulawesi, including low diversity overall, but highest at the Bulukumba site[17]. Data analysis in the coastal area of Dumai Barat district shows that the water quality is still good and can be tolerated by phytoplankton organisms with mesotrophic fertility[18]. Judging from the diversity value of the stations, the Belawan River is categorized as mild to moderate polluted. The diversity index (H') ranges from 1.212-2.617 (moderate) in the Brantas River, East Java, Indonesia[19]. The equitability value (E) ranges from 0.87 to 0.94, with the highest value recorded at station II and the lowest at station V. According to Muis *et al.*[20], the range of H' values is part of the water quality assessment along with the physical chemistry of water. The average phytoplankton abundance during the study was 19,256, 19,044 and 22,613 cells L^{-1} of 322 ind L^{-1} is classified as low abundance, which reflects low water fertility[21].

Correlation value: Correlation values between water quality parameters and the diversity index (Shannon-Wiener Diversity) are shown in Table 5. Based on Table 5 it can be seen that the diversity of phytoplankton is affected by DO. Although the DO obtained in this study ranged from 5.10-6.87 mg L^{-1}, these values were still in good condition needed by phytoplankton organisms, so that this parameter had a good influence on phytoplankton diversity. Dissolved oxygen in the Belawan River ranges from 3.8-5.3 mg L^{-1}, which was considered good because it is still within the quality standards set by PPRI No.22 of 2021, which is 3-6 mg L^{-1} [22].

In Table 5 it can be seen from the 2010 data show that temperature and light penetration greatly affect the diversity of phytoplankton. Temperatures range from 24-26 °C and light penetration ranges from 11-30 cm. The index system of the water temperature and its gradient changes effectively analyzed the influence of the reservoirs on river water temperature variations[23].

In Table 5, it can be seen that the 2015 data shows that dissolved oxygen (DO) greatly influences the diversity of phytoplankton. The DO ranges from 6.5-7.2 mg L^{-1}, this condition really supported the life of phytoplankton, where the water quality of the Belawan river greatly determines the condition of the Belawan River. The DO levels can recover benefit from reduction in the pollution load[24].

Model of the relationship between phytoplankton diversity and water quality: From the correlation analysis performed on the measured values of water quality parameters and the diversity of phytoplankton (Shannon-Wiener Diversity) in the Belawan River in 2010, 2015 and 2020, the obtained correlation value was given in Table 6. Based on the analysis of the correlation value obtained for the Belawan River management model, it can be analyzed using a polynomial regression model.

Polynomial Regression Model (for data 2010, 2015 and 2020):

$$y = -2.09235475 - 0.283821248x_1 - 0.000034042331x_2^2 - 0.000000317192297x_3^2 + 0.0000138747473x_4^2 - 0.0642412267x_5^2 + 0.0436398590x_6 - 0.0107999363x_7^2 + 0.0000469016376x_8^2$$

x_1 = Temperature
x_2 = Light concentration
x_3 = Light intensity
x_4 = Flow rate
x_5 = pH
x_6 = DO
x_7 = BOD_5
x_8 = COD
y = Phytoplankton diversity

The implications of this research include information on the number and type of phytoplankton and water quality that is needed to analyze the surrounding environment in the Belawan River. The environment and good water quality in the Belawan River are very important to continue to study because it is an important river for Medan City residents. The model for the relationship between water quality, environment and diversity of phytoplankton must continue to be analyzed every year, including the number of phytoplankton genus.

CONCLUSION

From the research conducted on the model of phytoplankton diversity and water quality in Belawan River, it can be conclude that: Phytoplankton obtained in all sampling stations was consisted of 23 genera, the highest abundance of phytoplankton was found in *Chaetoceros* sp., with the abundance value of 186 ind m^{-2} at station V. The highest diversity value (H') was recorded at station V of 2.30, whereas the lowest was at station I of 1.28. Phytoplankton diversity at all five stations is classified as low. The DO has a steady influence on phytoplankton diversity.

SIGNIFICANCE STATEMENT

It is very important to know the phytoplankton diversity model in the Belawan River, because phytoplankton is the main component in the food chain of aquatic ecosystems, producers of oxygen and determines the level of primary productivity and the level of water fertility. This model will be a further finding in the management of the Belawan River because this model can predict the condition of the Belawan river in the future, for the management of the river.

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