Analysis of the Suitability of Tropical Epipelic Diatoms to the Omnidia Diatom Database and Its Ability to Determine the Present Condition in Tuntang River Downstream, Demak, Indonesia

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Analysis of the Suitability of Tropical Epipelic Diatoms to the Omnidia Diatom Database and Its Ability to Determine the Present Condition in Tuntang River Downstream, Demak, Indonesia

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Abstract: Demak Regency experienced an increase in the human population from 2018-2021, affecting the water quality of the Tuntang River downstream. This research aims to evaluate the potency of a monitoring method based on diatom indices for water quality management. Water monitoring using the diatom indices will obtain more detailed water quality information. Diatoms are one of the bioindicators that can describe water quality well. Four stations were selected as sampling locations. Surface sediment was taken with a size of 5 cm, then diatom extraction using HCl and H_2O_2 10%. The results found 59 species, the dominant species being *Nitzschia palea* and *Fragilaria crotonensis*. Diatom indices that can present the best results are Eutrophication/Pollution Index (EPI-D), Biological Diatom Index (IBD), Generic Diatom Index (IDG), Spesific Polution Sensitivity Index (IPS), and Tropic Diatom Index (TDI). Studies on diatoms indices can be considered for water monitoring in Indonesia because Indonesian water quality monitoring still often measures physical and chemical aspects.

Keywords: ecological indicator; diatom indices; Tuntang River; water quality; river management

1. Introduction

Rapid population growth can affect surrounding environmental conditions. Many lands eventually experienced changes in function, one of which became residential. Several areas in the upstream and downstream regions of rivers in Central Java are experiencing land conversion into residential areas, agricultural land, and pond areas to meet the needs and activities of a growing population. According to Deng et al.[1], urbanization significantly contributes to changes in river systems and structures because it increases the risk of flooding. As the most developed area in Central Java, urbanization contributes to the rapid urbanization of this area, where 40% of the population lives in Central Java's northern coastal areas.

Demak Regency, one of the regencies in Central Java, experienced the most significant change, with the highest erosion rate of up to 279.1 m/year, eroding the coastline up to 5 km between 1998 and 2018[2]. Demak has one river that is in critical condition and is a priority, along with 108 other rivers: the Tuntang River[3]. The Tuntang River flows from Rawa Pening upstream to Ambawara, Semarang, Grobogan, and Demak before emptying into the Java Sea.

The Tuntang River has a role in society: agricultural irrigation and household water for washing and bathing; even the river flow that passes through the Salatiga Regency (before the Demak Regency) is used for drinking water. The increasing activity and population around the Tuntang River have caused problems related to water quality. People are still found throwing waste into the river. The condition of the river also experiences more nutrients due to fertiliser use in agriculture, the flow of which empties into the Tuntang River.

Research from Sawant et al[4], explains that water pollution from biological, toxic, organic, and inorganic sources affects 70% of Pune's surface and groundwater resources. The significant pollution was from untreated sewage.

If the Tuntang River continues to be polluted, its usability for the community will be affected. Monitoring the quality of water resources is one of the issues raised by Indonesia at the 10th World Water Forum, with the critical issues raised being Water Quality Assessment and Ecosystem Health. The Director General of Pollution and Environmental Damage Control found that there will be a 15% decline in river water quality by 2023[5]. The study of water quality monitoring in the downstream Tuntang River will help the ecosystem monitoring process and provide knowledge regarding biological studies using diatoms, which have yet to be widely carried out in Indonesia. Hence, monitoring is necessary to gauge water quality by employing swift and efficient bioindicators to address environmental changes[6].

Diatoms are Bacillariophyta algae that live in water[7]. Their silica cell walls protect their shape and allow them to be identified morphologically. They are sensitive to environmental changes and are frequently used as water quality indicators[8]. Diatoms have been used as an environmental quality parameter in Central Java, including Warna Lake[9,10], Pengilon Lake[10,11], and Cebong Lake[12].

Water quality testing in rivers using diatom indices has been conducted in the Bloukrans River in South Africa[13] and the Great Fish River in Africa[14]. Both presented the South African Diatom Index (SADI), which is based on African diatom species, but this indices has yet to be included in the Omnidia program. The Omnidia analysis includes 26 diatom indices, including IBD, IPS, IDG, DES, Sla., IDSE, Descy, IDAP, EPI-D, Lobo, DI-CH, Rott TI, Rott SI, TDIL, CEE, WAT, PDI, SHE, ACID, EPI-L, TDI, TDI4, LTDI2, Pfister SI, Pfister TI, ICMi[15-17].

This research aims to evaluate the potency of a monitoring method based on diatom indices for water quality management. Diatom studies using the diatom indices will obtain more detailed water quality information, such as integrating organic pollution, salinity, eutrophication[18,19], phosphorus concentrations, the influence of nitrogen or the interaction with pH is unknown mainly[19]. Diatom indices developed in Europe have been confirmed for successful application in other temperate regions, however, there is little information regarding their suitability for assessing water quality in subtropical or tropical zones[20].

The results of this research can serve as initial biomonitoring data for the downstream area of the Tuntang River, a vital water source for the community in Demak Regency. Additionally, these findings can help assess the efficacy of applying diatom indices in the tropical region of Indonesia.

2. Material and Methods

2.1 Study area

Demak Regency is located at 6º43'26" - 7º09'43" S and 110027’58” - 110048'47" E. Demak has an area of ± 1,149.07 km², consisting of ± 897.43 km² of land and ± 252.34 km² of ocean. The Tuntang River flows from Lake Rawa Pening to the Java Sea, flowing into Demak Regency in Central Java. The Tuntang River flows through three sub-districts: Karang Tengah District, Demak District, and Bonang District. Based on satellite imagery captured using the satellite[21], there were changes in land use functions between 2017 and 2022, with the area divided into settlements, agriculture, plantations, and ponds (Fig. 1).

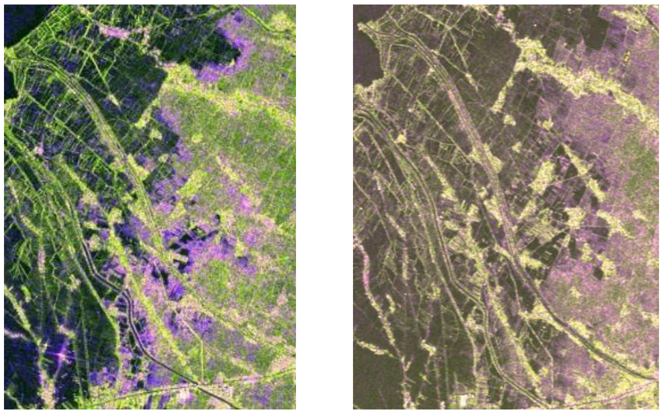


Fig. 1: Results of taking satellite images downstream of the Tuntang River (left: 2017; right: 2022)[22]. The green color that the natural vegetation area has changed into a purple color means it has changed into fish/shrimp ponds.

The sedimentation process is supported by the activities of the Demak people, such as agriculture, population growth, and industrialization. The increase in population increases from 2018-2021[23-25] (Fig. 2) (Table 1), the need for housing so that areas that were originally green slowly become residential areas (Fig. 1). This change in land use makes the Tuntang River vulnerable to pollution from various sources, such as organic substances, chemicals, and fuel.

Table 1. Percentage of population increasing.

Years	District		
	Karang Tengah	Bonang	Demak
2018-2019	**0.3%**	**0.8%**	**0.7%**
2019-2020	**7.3%**	**2.5%**	**6.8%**
2020-2021	**1.5%**	**0.6%**	**1.3%**

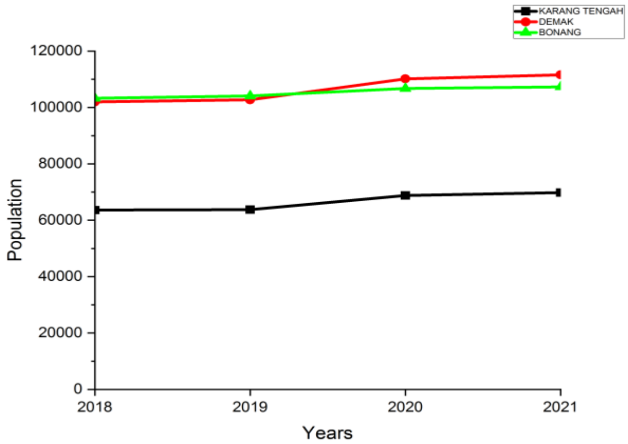


Fig. 2: Population data in Karang Tengah, Demak, and Bonang Districts 2018-2021[23-25]

On January 2022, four stations with different location characteristics were chosen using the purposive sampling method (Fig. 3). Station 1 (T1) is near the highway, Station 2 (T2) is near agriculture and waste disposal, Station 3 (T3) is near an agricultural inlet, and Station 4 (T4) is near a mangrove ecosystem.

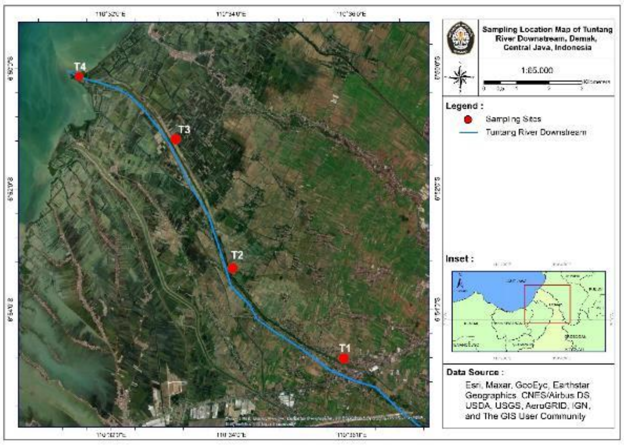


Fig. 3: Samping location map.

2.2 Diatom sampling, preparation, and analysis

Sediment digestion using the Soeprobowati et al. method[26], modified by the Battarbee method[27]. Surface sediment samples were collected with a dissection correr, and the top 1 cm of sediments weighing 5 grams was used for diatom counts and species identification. The sediment is placed in a plastic bag and transported to Diponegoro University's Acintya Prasada Laboratory. A solution of 10% HCl, 10% H_2O_2, and aquades are used in the diatom digestion process. This diatom digestion aims to separate diatoms from the sediment's adhering organic and inorganic materials so that they can be seen under a microscope. The 5 grams sample was digested for 3 hours in 50 ml of 10% HCl at 60-90ºC, then allowed to stand for 6-12 hours to remove the supernatant and replaced with distilled water eight times until the pH was neutral. Furthermore, digestion with 50 ml H_2O_2 10% was followed by the same treatment as digestion with 10% HCl. The goal of digestion is to reduce the amount of $CaCO_3$ in the sample because too much causes foam and to remove organic material[12].

After all digestion processes had been completed, diatom preparations were prepared. The hotplate was placed on the coverslip 22x22 mm, and 400 µl of diatom residue was added and attached to the slides with Naphrax, a diatom mountant with a refractive index 1.73. The minimum valve found to calculate the abundance of diatoms is 300 valves observed through a microscope with 1000x magnification. Identification was performed using standard literature and photomicrographs checked in AlgaBase.org[28].

2.3 Water quality

The water quality variable was measured three times at each station using the Horriba water checker U-50. Temperature (ºC), pH, Total Dissolved Solid (TDS), conductivity, and salinity are all measured in situ. Water sampling was measured by the Indonesian National Standard, SNI 6989.57-2008: the surface water samples were collected in 500ml sample bottles, labelled, and then put into a cooler. Water analysis at Diponegoro University's Environment Engineering Laboratory, where Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), phosphate, nitrate, nitrite, ammonia, N-Total, Cd, Cr, Cu, and Pb were tested.

2.4 Data analysis

Analysis of diatom abundance using past program 4.13 version, where diatom species with relative abundance values less than 2% (<2%) were removed because they are rare and do not exist in sufficient numbers to be statistically significant[29]. The discovered diatom communities were entered into the Omnidia 6.1 software to compute diatom indices (Table 2). The Omnidia database contains 28,000 diatom species from 920 genera, 7000 publications, 25 biological indicators, and 38 ecology statistics.

Table 2. List of diatom indices from Omnidia 6.1 database.

Diatom Indices	Type Indices
IBD (Biological Diatom Index)	General Pollution
IPS (Spesific Polution Sensitivity Index)	General Pollution
IDG (Generic Diatom Index)	General Pollution

Diatom Indices	Type Indices
DES (Descy's Index)	General Pollution
Sla. (Sládeček's Index)	Saprobity (BOD)
IDS/E (Louis-Leclercq Diatomic Index)	Saprobity
IDAP (Artois-Picardie Diatom Index)	General Pollution
EPI-D (Eutrophication/Pollution Index)	Pollution/Trophic Status
Lobo (Trophic-Saprobic Index)	Eutrophication
DI-CH (Swiss Diatom Index, Hurl)	Trophic Status
Rott TI (Rott's Trophic Metric)	Trophic Status
Rott SI (Rott's Saprobic Metric)	Saprobic Status
TDIL (Tropic Diatom Index)	Saprobity
CEE (Commission for Economical Community Metric-European Index)	General Pollution
WAT (Watanabe Index)	Saprobity (BOD)
TDI (Tropic Diatom Index)	Trophic Status/Eutrophication
IDP (Pampean Diatom Index)	Organic Pollution/Eutrophication
SHE (Steinber and Schiefele Trophic Metric)	Trophic Status
ACID	Acidity
ICMi (Italy) (Intercalibration Common Metric Index)	Nutrient Enrichment and Organic Pollution
Pfister SI (Pfister New Saprobic Index)	Saprobic Status
Pfister IT (Pfister New Trophic Index)	Trophic Status

Not all indices can interpret the water conditions in which the research is carried out. Therefore, selecting based on the species counted from the database is necessary. The indices will be used with a specified number of more than 70% (>70%). The diatom indices values range from 0-20, which can interpret water conditions (Table 3). The results of diatom indices will be displayed with a heatmap display using R Studio version 2022.07.1 with the "gplots" package.

Table 3. Diatom indices range value[30].

Score	Ecology State	Trophic State
17-20	Very Good	Oligotrophic
15-16,9	Good	Oligo-mesotrophic
12-14,9	Moderate	Mesotrophic
8-11,9	Poor	Meso-eutrophic
0-7,9	Bad	Eutrophic

Correlation analysis between diatom abundances (>2%) and water quality parameters was carried out using the non-parametric correlation spearman method using the R Studio 'corrplot' package version 2023.03.01. Graphic creation assisted with OriginPro 2023b 10.0.5.157 (learning edition) software.

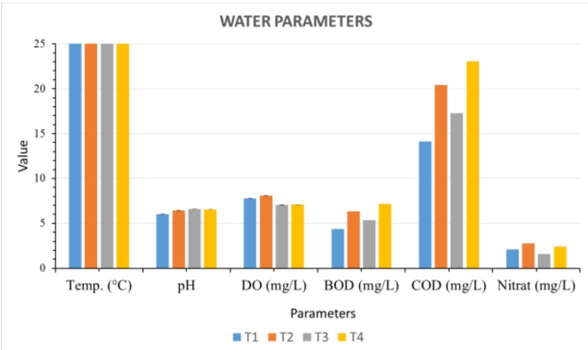
3. Results

3.1 Water quality

The results of water quality measurements, both in situ and in the laboratory, show no significant difference between stations (Fig. 4). The temperature at each station shows that the river is typical for a tropical environment. Indonesia has references in setting quality standards for pollution of river and sea waters as stated in the Government Regulation of the Republic of Indonesia no 21 of 2021[31] (Table 4), where the Tuntang River area is included in the class II category, which functions as water recreation, freshwater fish farming, animal husbandry, plants, and/or other designations that require the same water quality as usage. Based on the water quality analysis (Fig. 4), the BOD value exceeds the established standard, which is 3. The heavy metal Cr also exceeds the standard quality limit, while for Pb content, only station 4 (T4) is below the pollution limit.

Table 4. Standard score for water quality in river[31].

Parameters	Score	
BOD	3	Maximum
COD	25	Maximum
DO	4	Minimum
Nitrat	10	Maximum
Amoniak	0.2	Maximum
N-Total	15	Maximum
Cr	0.05	Minimum
Pb	0.03	Minimum



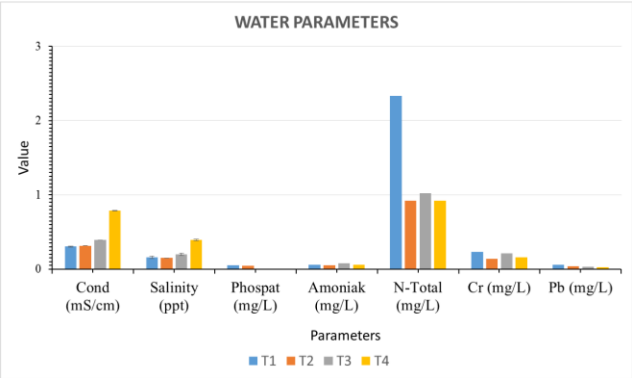


Fig. 4: Water quality measurements from all stations.

3.2 Diatom indices and community

Based on the identification results, 59 species from 28 genera were discovered (Fig. 5), ranging from 26 to 6513 ind/gr. The relative abundance of diatoms with a ratio above 2% contained 11 species (Fig. 5), namely *Cylindrotheca closterium* (CLCC), *Cyclotella meneghiniana* (CMEN), *Fragilaria crotonensis* (FCRO), *Fragilaria pinnata* (FPIN), *Fragilaria tenera* (FTEN), *Fragilaria ulna* var. *acus* (FUAC), *Melosira varians* (MVAR), *Nitzschia liebethruthii* (NLBT), *Nitzschia palea* (NPAL), *Navicula phyllepta* (NPHY), *Synedra famelica* (SFAM). Species with relative abundance above 10% were only *N. palea* (18%) dan *F. crotonensis* (13%).

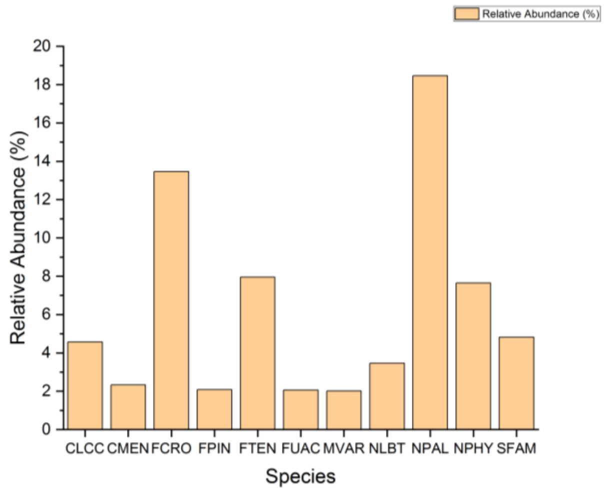


Fig. 5: Species with relative abundance >2%.

Based on calculating the diatom indices using Omnidia 6.1, the indices that included 70% of the diatom species were EPI-D, IBD, IDG, IPS, and TDI at all research stations (Fig. 6). The results of the EPI-D and IBD indices show that ecological conditions are in the poor-moderate range with mesotrophic to meso-eutrophic trophic status. While the IDG, IPS, and TDI indices provide a range of interpretations indicating environmental conditions are increasingly polluted, namely bad-poor and meso-eutrophic to eutrophic.

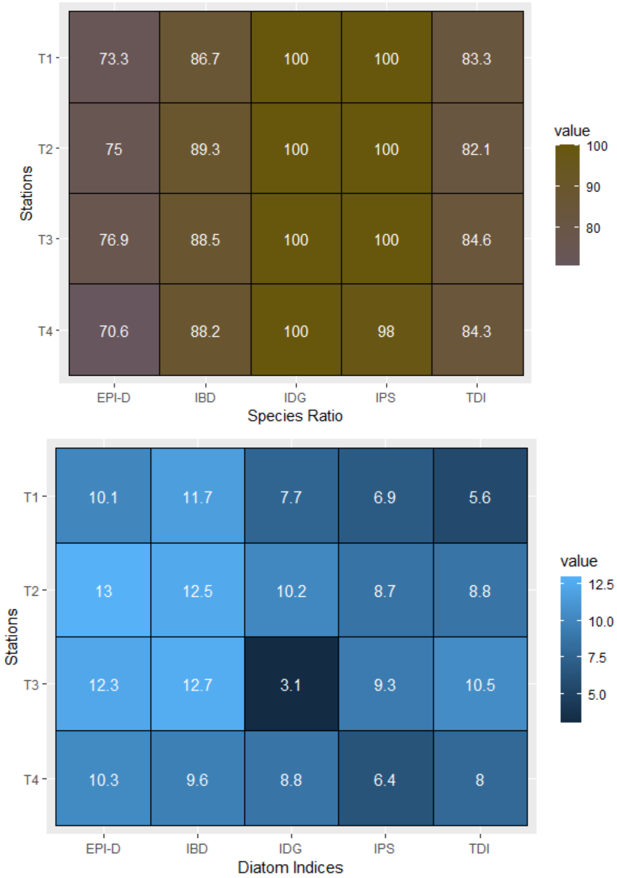


Fig. 6: Heatmap of species ratio (%) (brown-green) and diatom indices (blue).

3.3 Correlation between diatom and water quality

Because not all the data obtained were parametric, therefore Spearman correlation analysis was used for calculate the correlation between environmental variables and diatom species. Spearman correlation analysis was used because the normality test results showed that several variables were not normally distributed, so non-parametric analysis was used so that all parameters and diatoms could be tested. The correlation results showed that *F. tenera* and *N. phyllepta* had a strong positive relationship (r=1.00) with BOD and COD, while *S. famelica* had a positive relationship (r=1.00) with Cr (Fig. 7).

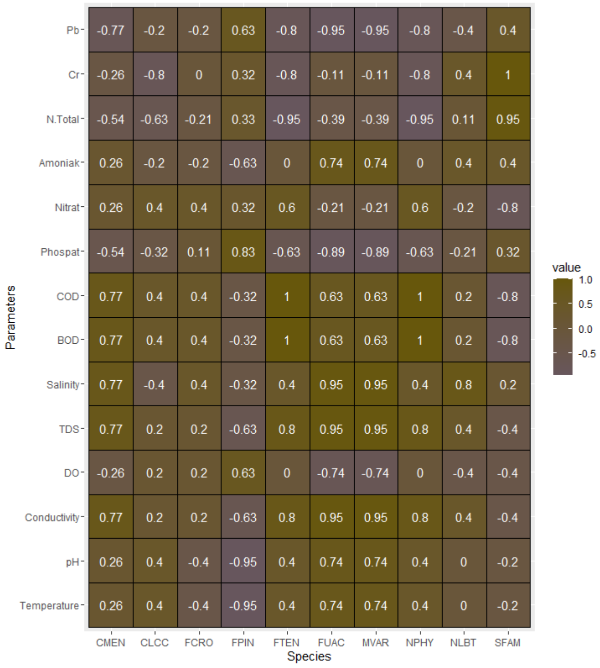


Fig. 7: Spearman non-parametric correlation; a positive relationship occurs when the number gets closer to 1, and a negative relationship occurs when the number approaches -1.

4. Discussion

4.1 Water quality and pollution in Tuntang River downstream

The main problem in the Tuntang River is sedimentation, which makes the river shallow. As the depth of the river decreases, the cross-sectional area of the water will decrease, which can cause flooding. This problem is then compounded by the influence of seawater in the river's downstream area, which can accelerate the process of sedimentation and water overflow. On the other hand, the larger the agricultural area, ponds and houses, the more pollutant load entering the river[32)].

One water quality phenomenon is rain, where the rain differs in the upstream and downstream areas, but the river flow continues downstream. The rain that caused flooding in the Tuntang River affected nutrient content, sediment suspension, turbidity, BOD, and conductivity[33)]. The abundance of algal biomass (phytoplankton[34)] and diatoms), zooplankton, and fish increases after rainfall. Research conducted on the Hangtangang River, South Korea, showed that the quality of the waters became polluted after the volume of the river increased due to rain[35)]. This shows that rainfall affects the flow of water discharge volume and water quality.

Research conducted by Mancuso et al.[36)] in Lake Muskegon, USA, shows that the lake's silica content also increased compared to before 2019, when rainfall was lower. This indicates that an abundance of silica content supports diatom taxa to grow. Problems downstream of the Tuntang River are also increasing due to the carrying of waste from the upstream and middle areas to the downstream, which results in the accumulation of waste.

The high BOD indicates that the concentration of organic matter in the waters also increases downstream[37)]. The greater the BOD value, the more polluted the waters are, originating from domestic and other waste[38)]. The heavy metals Cr and Pb also exceed the standard quality limits, indicating that household and industrial waste disposal flows into the Tuntang River. According to Nugraha et al.[39)], the Tuntang River's water quality meets quality standards for slightly polluted water. Land use changes influence the Tuntang River's water quality; adding residential land can worsen the water quality. Adding residential land also increases BOD parameters in river water.

This causes problems with river water quality and worsens due to the many activities of people who dispose of waste directly into the river. Setyowati's research[40)] downstream of the Cisanggarung River, Cirebon, where the quality of the river is still influenced by community activities on the riverbanks, shows that the contents of BOD, COD, nitrate, and coliform exceed the established standards.

The BOD value at station 4 has the highest content of the four measured stations. Mangrove ecosystems have leaf litter decomposed by microorganisms, and the high organic matter content can also raise the BOD value. This high BOD condition in the mangrove ecosystem was also found in Daroini and Apri's[41)] research in Prancak Village, Bangkalan waters.

Based on the grouping of total N content by Vollenweider[42)], there are three categories of water trophic status, namely oligotrophic (200-400 μg), mesotrophic (300-650 μg), and eutrophic (500-1500 μg). The total N calculation in this study is at the eutrophic level when referring to this grouping. This eutrophic condition is also supported by cloudy, green to brown, and smelly water conditions. The smell can come from waste pollution and the circulation of the decomposition of H_2S gas by bacteria toward nitrogen compounds.

4.2 Diatom community

The dominant genera, *Nitzschia* and *Navicula*, suggest that the genus is associated with suspended sediments and/or is a typical resident of lotic systems where sedimentation frequently occurs[43)]. Because diatoms are a good indicator of water quality, their identification can help describe environmental conditions downstream of the Tuntang River. Both genera survive by moving through sediments toward the light and avoiding being buried under particles, which prevents them from being deposited[44)]. In this study, *N. palea* was discovered to have motility; this species was most abundant at station 4, where the muddy sediment conditions.

At stations 1 and 4, *N. palea* was dominant, while *F. crotonensis* was dominant at stations 2 and 3. Because the size of their motility and the condition of their nuclear membranes quickly reflected quality effects, the *N. palea* species could indicate soil quality in rivers from agricultural areas. After only 48 hours of pollution exposure, sediment[45]. The emergence of the dominance of *F. crotonensis* indicates that the environment contains a reasonably high Si content[46], high conductivity[47], and is a pollution-tolerant species[48].

Station 4 has a higher number of species (50 species) than the other stations because, at the mouth of the Tuntang River, there are all types of habitats for diatom species. In comparison, Soeprobowati and Suedy[49] found 147 species in mangrove ecosystems along the North Coast of Central Java, Hariyati et al.[50] found 97 species in the estuary of the East Flood Canal of Semarang, Nurimansyah et al.[51] found 36 species in the estuary of the East Flood Canal Semarang, and Soeprobowati et al.[52] also conducted monitoring in the Semarang East Flood Canal by obtaining 39 species. Diatoms are one of the main contributors (along with phytoplankton) in the primary aquatic cycle in mangrove ecosystems[53]; apart from that, mangrove litter fall will decompose and produce nutrients which include nitrate and phosphate, which dissolve in water so that it will support the growth process of diatoms.

Besides determining the condition of environmental changes, the discovery of marine species can indicate the influence of seawater on settlements. The species that shows the influence of seawater salinity is *C. closterium*, which, together with *Pleurosigma elongatum, Tryblionella calida, Tryblionella apiculata*, and *Tryblionella littoralis*, are marine species found in the lower reaches of the Tuntang River[54]. The most recent flood event occurred in January 2023, resulting in various disruptions that hindered transportation. The train line along the north coast was particularly affected as it was rendered inoperable due to water accumulation. Furthermore, the rising seawater towards the mainland led to seawater intrusion. This intrusion refers to the saltwater entry into coastal areas, resulting from lowering groundwater levels due to groundwater movement in the system[55]. The cones of depression and the ascension in the groundwater system contribute to this process. Consequently, the residents of Demak have been experiencing salty-tasting groundwater, affecting their daily needs.

The abundance of *N. palea* and *F. crotonensis* species indicates that the nutrients in the environment are pretty abundant, and pollution occurs[56], as well as experiencing eutrophication. Conformity of pollution findings through physical and chemical calculations of water samples with the composition of the diatoms found indicates that diatoms have a good bioindicator function. Diatoms have great species diversity[57], short generation times[58], and the ability to respond directly and sensitively to environmental changes[59]. These anthropogenic activities have accelerated changes in river systems through pollution[60], habitat destruction, invasion of alien species, manipulation of hydrology, and other physical disturbances. Besides the obvious physical impacts, human activities have many adverse impacts on water quality and the biotic communities that inhabit rivers[61].

4.3 Diatom indices

Diatom indices for aquatic environment analysis are popular in lotic and lentic waters. Diatom-based indices simplify the complex ecology of lotic systems because stream health can be assessed using a simple one-metric calculation[62]. The results of each index indicate a different interpretation of river conditions because each index has its own calculation method, and the database used still includes diatoms found in Europe[14].

Because the IDG index is limited to the genus level to simplify the technique, IDG represent 100% of the species[63]. In Poland[64] and South Africa[6,14], IDG performed well in monitoring water quality. The environmental quality of all stations can be described by five indices: EPI-D, IBD, IDG, IPS, and TDI.

At station 1, the EPI-D and IBD indices provide information on the condition of the waters in the meso-eutrophic state. In contrast, the IDG, IPS, and TDI indices indicate eutrophic status. This eutrophication condition is supported by the abundance of *N. palea*, which has a relative abundance value of 26%. The sufficient abundance of these species indicates that the nutrients in the environment are pretty abundant, and pollution occurs [56]. *N. palea* is a bioindicator of water quality because it is tolerant of environmental pollution[65], resistant to pollution caused by organics and heavy metals, and is often found in eutrophic waters[66]. This can happen considering that at station 1, people still use the river as one of their household needs, so pollution from detergents and waste can still enter the waters.

In station 2, the EPI-D and IBD indices indicate mesotrophic conditions, while the IDG, IPS, and TDI indices indicate meso-eutrophic conditions. This condition is supported by the abundance of *F. crotonensis*, which also has a wide distribution in freshwater[67]. The discovery of this species in research in Rotota[68] indicates an increase in nitrogen concentrations and eutrophication processes in the waters. Given the increasing population, this change indicates the result of human anthropogenic activities, such as agriculture, plantations, and changes in land use for settlements[69], particularly in the three sub-districts traversed by the lower reaches of the Tuntang River. Species that indicate a meso-eutrophic state of the environment include: *A. ambigua*, *C. placentula*, *G. parvulum* var. *parvulum*, *M. atomus*, *M. varians*, *N. rostellata*, *N. viridula*, *N. palea*, *N. microcephala*, *P. borealis*, dan *S. brebissonii*[70]. While the oligotrophic status is characterized by the emergence of species *A. macrocephalum*, *E. minutum*, *E. neogracile*, *E. bilunaris*, *E. incisa*, *F. tenera*, *G. pumilum*, dan *L. acidoclinata*[71].

At station 3, the EPI-D and IBD indexes indicate mesotrophic conditions, while the IPS and TDI indices indicate meso-eutrophic status; only the IDG index indicates eutrophic conditions. Then, at station 4, the EPI-

D, IBD, IDG, and TDI indices indicated meso-eutrophic conditions; only the IPS index indicated eutrophic conditions. The distribution of the diatoms found was also relatively the same, namely the abundance of *N. palea* and *F. crotonensis*. Research conducted by Blanco et al.[68] in six lakes in Spain shows that the IPS index can provide information on lentic ecosystems because of its strong correlation with total nitrogen concentrations. A low IDG score is also a valuable indication of pollution or impacts within the lake[72] originating from inflows entering the lake as runoff from rural development, forestry, and agriculture in the lake catchment.

Each taxon of diatoms has an optimal value and tolerance range to provide information about nutrient conditions such as phosphate and nitrate so that they have a variety of responses to the physical and chemical conditions of the waters[73]. Research conducted by Szabó et al.[74] in Romania found that the species of *A. formosa, F. tenera, F. nanana, F. nanoides, D. pseudostelligera* indicated eutrophic conditions. In contrast, research by Spitale et al.[75] revealed that some species of the *Fragilaria* genus are very competitive in waters with a high N:P ratio derived from high nitrite to nitrate and produced in oligotrophic waters in Lake Balma.

The results of four sampling stations downstream of the Tuntang River indicate that the river is in a mesotrophic to eutrophic trophic state. Diatom indices were created because it was discovered that they respond to water quality gradients such as nutrients[76], ion concentrations[77], and organic loading (e.g., WAT[78]). Differences in environmental conditions based on diatom indices can occur because the environment at each station is different; additionally, many dynamic interactions between the physical, chemical and biological processes affect the diatom community composition that cannot be quantified[14].

4.4 Diatom community and correlation with water quality

According to Spearman's non-parametric correlation test, BOD and COD had a strong relationship (r= 1) with *F. tenera*, and *N. phyllepta*. The biochemical oxygen demand (BOD) is a common parameter used to assess organic pollution in water systems. The amount of oxygen that microorganisms consume in the aerobic metabolism of organic matter in the water can be used to detect this parameter. The dominant taxa capable of living in heavy metal-polluted environments are *Fragilaria*[79]. Cr has a strong relationship with *S. famelica* (r= 1). Despite the toxic effects of high heavy metal concentrations on diatoms, some can live in degraded and polluted freshwater from marine and terrestrial environments. Metals' effects on diatom communities have been studied in a variety of polluted watersheds as well as in laboratory experiments[80]. On the other hand, Pandey et al.[81] proposed that to understand the responses of algal communities to metals, algal criteria for biomonitoring these pollutants should be developed.

The nutrients indeed influence the dynamics of diatom abundance in river water bodies. However, heavy metal contamination decreases the abundance of several diatoms that have no tolerance to heavy metals. The content of Ca and S in water is used to form the cell walls of silica diatoms[82]. P content is in the structural framework of DNA, RNA, ATP, and phospholipids, which form cell membranes. *N. angusta, G. acuminatum, C. solea, F. capitata, C. placentula, P. divergens, P. gibba, P. viridis* were found in waters near industrial areas of Poland[82].

Diatoms as bioindicators have varying sensitivity levels (depending on the species and the pollution that occurs) and a tolerance range for environmental pollution[83]. The abundance of microalgae with salinity positively correlates with spatial distribution[84]. *F. ulna* var *acus* and *M. varians* strongly correlated with Total Dissolved Solid (TDS) (r=0.94). TDS measures the amount of dissolved substances such as potassium, sodium, chloride, carbonate, sulfate, calcium, and magnesium in the water[85]. Research conducted by Ahmed et al.[86] on the coast of Port Dickson showed that the distribution of epipelic diatoms such as *C. placentula, D. crabro, E. laevis, Actinoptychus sp., Amphora sp.,* and *Coscinodiscus sp.* gives a positive relationship with temperature, TSS, SiO_2, OM, NH_3, NO_2^-, pH, Chl-a, and TDS.

5. Conclusions

Conditions downstream of the Tuntang River require monitoring and preventive action to prevent the addition of pollutant loads in water bodies. The condition of the downstream in this study was seen through the composition of the epipelic diatoms and the calculation of the diatom indices. As a result, 59 species were found, of which *N. palea* and *F. crotonensis* were abundant in the four study locations. The abundance of these species indicates that the waters are undergoing a eutrophication process, supported by the interpretation of the results of the diatom indices calculations, which indicate that the waters are in mesotrophic to eutrophic conditions. EPI-D, IBD, IDG, IPS, and TDI are the diatom indices that play a role in this calculation. This study has shown that diatom indices respond to ultimate environmental factors such as land use and water quality changes. Nonetheless, the intricacy of diatom responses to environmental factors and the possibility of regional discrepancies underscore the necessity for diatom-based indices to be utilized with meticulous attention to local conditions and, when warranted, modified for particular regions or river types to guarantee precise water quality evaluation. Diatom indices can complete the water quality measurement by analyzing each appropriate chemical physics factor.

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