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Water quality assessment based on saprobic index of phytoplankton with emphasis on several potentially Harmful Algal Blooms (HABs)

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Abstract. *Nurdin J, Aziz R, Nur L, Janra MN. 2025. Water quality assessment based on saprobic index of phytoplankton with emphasis on several potentially Harmful Algal Blooms (HABs). Biodiversitas 26: 890-899.* The estuary is one of the most productive ecosystems on earth due to the accumulation of all materials, including nutrients, from the upstream to the downstream. This ecosystem also plays a role in habitat function for many living organisms, such as protists, bacteria, invertebrates, and vertebrates. However, this ecosystem may suffer from the accumulation of waste, which leads to pollution. This study aims to investigate and update the information regarding water quality based on the phytoplankton from the estuaries in Padang City, West Sumatra Province, Indonesia, and its potential as Harmful Algal Blooms (HABs). Sampling was conducted from November to December 2023 at six estuaries in Padang, and several formulas, such as diversity, equitability, dominance, Bray-Curtis, and saprobic indices, were used to analyze all of the data, respectively. A total of 130 species of phytoplankton belonging to five classes were identified, where Bacillariophyceae showed the highest diversity (98 species). Overall, the phytoplankton was moderate to highly diverse ($2.95 \leq H' \leq 3.93$), highly equitable ($0.73 \leq E_H \leq 0.93$), low dominant species ($0.03 \leq C \leq 0.11$), and the highest similarity using Bray-Curtis occur between station 5 and station 6. At the same time, the Saprobic index was constant (X: 1.00). The pollution status at these estuaries could be considered light at the β-mesosaprobic or β-meso/oligosaprobic phase. In addition, 16 phytoplankton species were identified as HABs from these estuaries, including *Alexandrium, Dinophysis, Prorocentrum,* and *Pseudo-nitzschia*. Reducing the source of pollution from organic or non-organic materials, where the majority come from household waste disposal, may keep the health and quality of the rivers and estuaries in Padang.

Keywords: Estuary, freshwater algae, mesosaprobic, oligosaprobic, pollution

INTRODUCTION

Water quality in estuaries is highly varied and constantly fluctuating due to a mixture of fresh and seawater, which is influenced by inner and outer factors (Semeniuk 2016). The mixing of those waters causes variability in salinity, where some places are hyposaline (Schettini et al. 2017; Valle-Levinson 2022; Largier 2023) while others can be hypersaline (Van Diggelen and Montagna 2016; Taebi et al. 2024). As a result, the biotic components follow the respected salinity and facilitate the occurrence of various organisms such as fishes, crustaceans, mollusks, planktons, and many others (Padisák and Naselli-Flores 2021; Lennartz et al. 2023). The occurrence of these organisms, in turn, acts as an inner factor that reflects the condition and healthiness of aquatic ecosystems. Therefore, these organisms have been used as biological indicators of aquatic ecosystem health (Parmar et al. 2016).

Phytoplankton are the most common organisms in the aquatic ecosystem, serve as the primary producers within the water, and are the base of food webs in aqueous environments (D'Costa and Naik 2019). The abundance of phytoplankton in the water column reflects the environmental conditions, yet their potential as bioindicators of aquatic ecosystems is mostly ignored (Yusuf 2020). The use of phytoplankton as a bioindicator for aquatic ecosystems is superlative to the use of animals, as they are simple, reliable in quantifying the changes of water quality, applicable over large geographic areas as well as provide up-to-date information regarding habitat condition and natural variability (D'Costa and Naik 2019). Furthermore, phytoplankton are useful for short- and long-term observation of environmental changes, especially in the rapid detection of pollutants contained in aquatic bodies to provide data regarding disturbed ecosystems (Ajayan and Ajit-Kumar 2017).

On the other hand, the rapid growth and massive density of phytoplankton within aquatic bodies, especially microalgae, can cause algal blooming (NOAA 2019). This phenomenon, while currently a challenge, can be addressed to alleviate the ecosystem's distress caused by hypoxia or anoxia through acidification. For local communities, the bloom creates unsightly views, and taste and odor issues hamper recreation, tourism, and drinking water provision. Some phytoplankton species that can secrete toxins are Harmful Algal Blooms (HABs), such as dinoflagellates, diatoms, and cyanobacteria (Zhang et al. 2023). The HABs contribute to reducing water quality and ecosystem health, but with concerted efforts, this can be reversed. When massive amounts of cyanobacteria or other microalgae decay, the process depletes aquatic oxygen, sometimes resulting in 'dead zones.' These zones are mortal for fishes, crustaceans, mollusks, and others; they harm the economic sector (Gatz 2019).

Some indices have been developed through time to measure algal conditions, such as Kothe's index, Palmer's index, Saprobic index, Descy's index, Index of Pollution Sensitivity (IPS), generic diatom index, CEE index, Trophic diatom index, and IDAP index. These indices assess the quality and pollution level in the water based on the algal community. Moreover, one of them, the saprobic index, is considered the most reliable index to indicate aquatic pollution levels since it considers the density and composition of aquatic organisms and considers them as bioindicators for water bodies (De Pauw and Vanhooren 1983). It has been applied to assess water pollution at many localities in Indonesia (Arsad et al. 2021; Samudra et al. 2022).

Padang City is on the western coastline of Sumatra, Indonesia, with some estuaries, a vast oceanic zone, and small adjacent islands. The harmful algal blooms phenomena ever occurred at the sea of this city (Rachman 2019), and according to the investigation, *Noctiluca scintillans* was among the phytoplankton species responsible for this happening (Nofrita 2020). Despite no serious impact recorded from these phenomena, the prolonged blooming of dinoflagellate could damage this city's sea and estuary zones. This could potentially lead to a decline in fish stocks, affecting the livelihoods of local communities. In addition, the phytoplankton community in West Sumatra has been previously studied, where most phytoplankton were assessed based on their chlorophyll-a content (Arta et al. 2016; Pelly et al. 2020; Nurdin et al. 2023). Further research on the phytoplankton using different methodologies will help provide more information and a better understanding of the essential water quality for the surrounding communities. This study is intended to investigate and update the information regarding water quality using phytoplankton sampled from estuaries in Padang and evaluate their potential as Harmful Algal Blooms (HABs).

MATERIALS AND METHODS

Study area

This study was conducted from November to December 2023 at six estuaries in Padang City, West Sumatra Province, Indonesia. The estuaries are from six rivers (Sungai, Banda or Batang in Bahasa or Padang language) traversing Padang, i.e., Sungai Pisang, Batang Arau, Banda Bakali, Batang Kuranji, Batang Air Dingin and Batang Kandis (Figure 1).

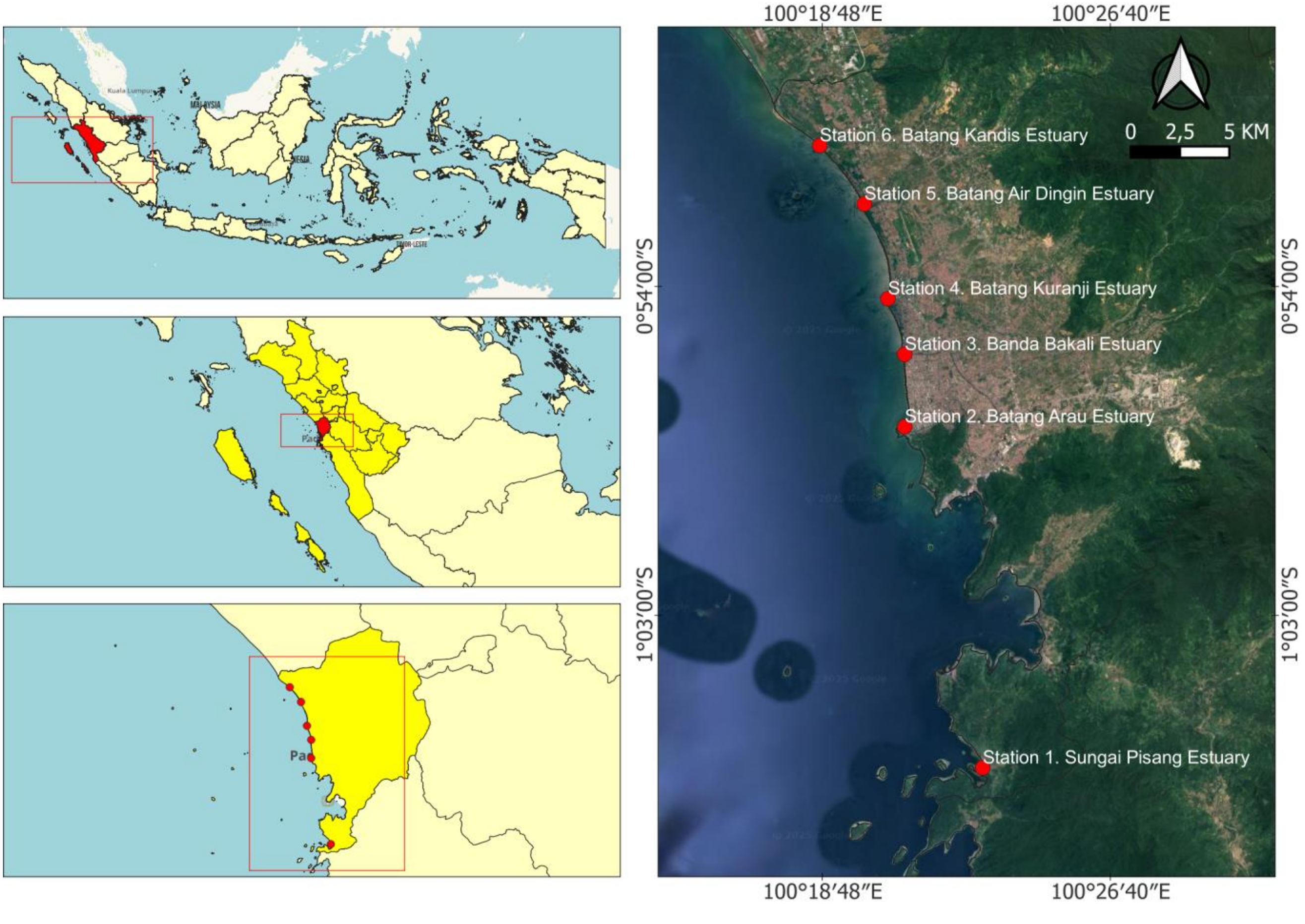

Figure 1. The map showing sampling stations at six estuaries in Padang City, West Sumatra, Indonesia

Sampling procedure

Samples were collected one time at each site, and approximately 100 liters of water from each estuary were scooped with a bucket and filtered into a plankton net (mesh size: 25 microns) with three replicates. As much as 20 mL filtrate was stored in a sampling bottle after being fixed with 4% formaldehyde and 5 drops of Lugol's solution. During the sampling session, some water variables were directly measured, including water surface temperature, salinity, pH, water clarity, Dissolved Oxygen (DO), and Carbon Dioxide (CO_2).

Meanwhile, for Biological Oxygen Demand (BOD_5), Total Suspended Solids (TSS), Nitrate (NO_3), and Phosphate (PO_4) were tested at the laboratory. Temperature and salinity with a digital AZ instrument (AZ 8371), pH with an Adwa instrument (AD12), water clarity with Sacchi disc, DO, and CO2 with an AZ instrument (AZ 8402). TSS with SNI 06-6989.04:2004, NO_3 with APHA 1992:4005-NO3.4-87, and PO_4 with Spectrophotometry. All samples were then observed under a compound microscope using a Sedgewick Rafter counting chamber. Each phytoplankton species was counted and identified following proper guidance (Tan et al. 2016; Castellani and Edwards 2017; Hi et al. 2019). The taxonomy referred to materials provided online at algaebase.org and marinespecies.org.

Data analysis

Several ecological indices were used to calculate the data. Shannon-Weaver index (H') is for phytoplankton species diversity, Equitability index (E_H) to measure the evenness of individuals in the community among estuaries, Dominance index (C) to assess the dominance of certain phytoplankton, Bray-Curtis index (BC) to determine the similarity in the species composition among all observed station and Saprobic index (X) for the degree of pollution in the water body (Table 1). The formulas are as follows:

Shannon-Weaver index (H')

$$H' = -\sum \left(\frac{ni}{N}\right) \ln \left(\frac{ni}{N}\right)$$

Where H' represents the diversity index of Shannon-Weaver; ni is the number of individuals of species I; N is the total number of individuals of all species. The diversity can be categorized as very low for H' less than 1.0, low for H' between 1.1 to 2.0, moderate if H' lays between 2.1 to 3.0, high if H' is between 3.1 to 4.0, and very high if H' above 4.0 (Shannon and Weaver 1949).

Equitability index (E_H)

$$E_H = \frac{H}{Hmax} = \frac{H}{\ln S}$$

Where E_H denotes Shannon's equitability, H' is Shannon's diversity index, and S is the total number of species in the community. Shannon's equitability has a value between 0 and 1; the closer it is to 1, the more uniform the population of different species in the community (Magurran 2004).

Dominance index (C)

$$C = \sum \left(\frac{ni}{N}\right)^2$$

Where, C is Simpson dominance index; ni is number of individuals of species i; N is total individuals of all species. Species dominance in a community is said to be low if it lies between 0-0.5, moderate from 0.5-0.75, and high from 0.75-1.0 (Magurran 2004).

Bray-Curtis index (BC)

$$(BC_{jk}) = \frac{\sum_i |x_{ji} - x_{ki}|}{\sum_i |x_{ji} + x_{ki}|}$$

Where BC is the Bray-Curtis index, j and k are the represent of two sites, ji is total individuals at site j and ki is total individuals at site k. The Bray-Curtis index has a value between 0 and 1; the closer it is to 1, the more similar the population of different species in that community (Bray and Curtis 1957).

Saprobic index (X)

$$X = \frac{C + 3D - B - 3A}{A + B + C + D}$$

Where X is the Saprobic Coefficient, with a value between –3 to +3; A is the number of Ciliates species (poly-saprobic); B is the number of species of Euglenophyta species (α-meso-saprobic); C is number of Chlorococcales and Diatoms species (β-meso-saprobic); D is number of species from Peridinians+ Chrysophyceae+ Conjugate group (oligosaprobic) (Dresscher and van der Mark 1976).

A one-way Analysis of Variance (ANOVA) was employed to assess any significant difference in the phytoplankton composition from six stations. All of the data were analyzed using the PAST (PAleontological STatistics) software vers. 4.17 (Hammer et al. 2001).

Table 1. Water pollution levels based on Saprobic index (Drescher and van der Mark 1976)

Pollutant source	**Pollution level**	**Saprobic phase**	**Saprobic index value**
Organic matters	Very heavy	Polysaprobic	-3 to -2
		Poly/α-mesosaprobic	-2 to -1.5
	Heavy	α-meso/polysaprobic	-1.5 to -1
		α-mesosaprobic	-1 to -0.5
Organic and inorganic substances	Medium	α/β-mesosaprobic	-0.5 to 0
		β/α-mesosaprobic	0 to 0.5
	Light	β-mesosaprobic	0.5 to 1
		β-meso/oligosaprobic	1 to 1.5
Few organic and inorganic substances	Very light	Oligo/β-mesosaprobic	1.5 to 2
		Oligosaprobic	2 to 3

RESULTS AND DISCUSSION

Environmental variables

Measurements on the mean of 10 environmental variables, i.e., water surface temperature, salinity, pH, water clarity, DO, CO2, BOD, TSS, NO3, and PO_4, are presented in Table 2. The water surface temperature seemed to be uniformly 30.3-30.7ºC at all stations during field time, while salinity and pH slightly fluctuated, respectively, measuring 21-30.3% and 6-7. Water clarity at Station 1 is significantly higher than at other stations. At all stations, DO ranged from 5.52 to 7.29, CO_2 measured 0-0.24, and BOD was detected as normal (0.96-1.13). The TSS moderately varied (20-60 mg/L), where Station 5 was measured the highest and Station 1 the lowest, NO_3 ranged from 0.003 to 0.07, and PO_4 highly fluctuated, from 0.04 to 1.2.

The surface temperature of Indonesian seawater ranged from ~27°C to ~31°C, classified as warm water (Kusuma et al. 2017); the measurement in this study aligned with it. The combination of horizontal heat flow from the Pacific Ocean toward the Indian Ocean (including Indonesia) and heat transport affect the warming of the sea (Iskandar et al. 2020). Within the estuary ecosystem, water temperature is a very important factor affecting DO concentration, the life and distribution of aquatic organisms, photosynthesis, metabolism of aquatic organisms, and the sensitivity of organisms to toxic wastes, parasites, as well as diseases (NOAA 2024).

Salinity is widely recognized as a dominant environmental variable in estuarine systems with various sizes, shapes, depths, and other characteristics (Johns and Heger 2018). Salinity in the Sumatra Sea (particularly the Indian Ocean) regularly fluctuates from time to time and generally ranges from 33-35% (Purba et al. 2018). The tidal movement influences this phenomenon, the input of freshwater runoff from the terrestrial zone or mainland, which becomes more significant during the rainy season and the size of the river or estuary (Barik et al. 2018).

Water acidity (pH) is another factor that regularly fluctuates after accumulating biological, chemical, and physical substances. Short- or long-term acidity in water bodies is mostly affected by anthropogenic activities. Over-accumulation of nutrients from the agricultural sector, for example, triggers algal blooming, which suddenly increases water acidity. When water acidity is lower than 5.0 or more than 9.0, it tremendously affects the survival of aquatic plants and animals. The solubility of iron and copper becomes lower when water pH changes. Therefore, when pH decreases, the toxicity will remain in the estuary water (NOAA 2024).

Water clarity measures the depth of sunlight penetrating through the water column. Water clarity can vary naturally due to tides, storm events, wind patterns, and changes in sunlight. Clearwater is characterized by low concentrations of suspended particles of soil and/or algae. In contrast, turbid water is marked with heavy suspended particles, which then cloud the visibility by absorbing and scattering penetrated light. As water clarity affects light penetration, it indirectly implies the diversity and productivity of aquatic ecosystems. Clearer water allows more sunlight to reach submerged aquatic vegetation, which helps them produce more oxygen. More oxygen nourishes more diversity of aquatic organisms, which in turn provides food for fish, waterfowl, and aquatic mammals. Clear waters are generally more aesthetic and scenic, which is useful for recreational purposes (Kitheka et al. 2016; Kim et al. 2024).

The DO concentration in estuary areas significantly fluctuates, influenced by the depth and temperature of the aquatic body. The higher the temperatures, the lower the DO concentration, and vice versa. The difference in aquatic layers between the surface and bottom parts (vertical stratification) also influences DO concentration, where the deeper it goes, the lower the concentration. A minimum of 5 mg/L oxygen concentration is ideally able to support aquatic organisms; the lowering concentration can impose stress until it reaches less than 3 mg/L, which is lethal for most organisms. Aquatic pollution is the main factor in reducing oxygen concentration in water, despite low oxygen conditions that may occur naturally at undisturbed estuaries (Haddout et al. 2022; Hutchings et al. 2024; Shen and Qin 2024).

Carbon exists both in the atmosphere and in water. Alkalinity, acidity, Carbon dioxide (CO_2), pH, total inorganic carbon, and basic water substrate are the components of the inorganic carbon complex within aquatic ecosystems. These components essentially influence aquatic plants' photosynthesis and water acidity. It was recommended that diluted Carbon dioxide (CO2) should not exceed 15 ppm in aquatic bodies (USEPA 2006), which this study fully complied with as it was in much lower concentration (Table 2).

Table 2. The mean of physicochemical variables at 6 estuaries in Padang City, West Sumatra, Indonesia

Station	Temperature (ºC)	Saline (%)	pH	Water clarity (m)	BOD (mg/L)	DO (ppm)	CO_2 (ppm)	TSS (mg/L)	PO_4 (mg/L)	NO_3 (mg/L)
1	30.7	30.3	7	15.3	1.13	6.70	0	20	0.096	0.003
2	30.7	24	6.56	3	1.04	5.52	0.24	40	1.208	0.074
3	30.3	21	6.57	4.34	0.96	6.26	0.07	30	0.079	0.005
4	30.7	23.3	6.60	3	1.03	6.60	0.24	30	0.085	0.026
5	30.7	21	6.93	5	1.05	7.29	0	60	0.049	0.005
6	30.7	27	6.79	3.66	1.03	7.15	0	40	0.040	0.007

The amount of BOD was correlated with DO concentration in the estuaries, as the increase in BOD causes a decrement in oxygen concentration. In most cases, the significant BOD level for unpolluted or natural water was <5 mg/L. This indicated that the BOD concentration lowers DO concentration, which stresses the living organisms and might lead to death (Jouanneau et al. 2014; Saraswati et al. 2018). The BOD level recorded in this study was in good condition, meaning the estuaries in Padang are supportive of the living of aquatic organisms. The factor TSS indicates the level of sediment in the water. During the rainy season, high rainfall and elevated surface runoff increase water turbidity and reduce water transparency, lowering light intensity and algal density. Reduced light penetration after being hampered by suspended sediment declines algal growth (Hilaluddin et al. 2020) and chlorophyll-a concentration (Singh and Singh 2015; Metsoviti et al. 2020). Inorganic nitrogen consists of ammonia, nitrite, and nitrate. Ammonia is the primary product of microbial degradation of organic nitrogen; when not used for growth by autotrophic algae, vascular macrophytes, and microbial heterotrophs, it may be then oxidized through nitrification into nitrite and nitrate. Varying proportions of organic nitrogen contribute the least to over-enrichment problems at the estuary, as nitrate enrichment problems can happen locally and further seaward (Sanders and Laanbroek 2018; Nengwang et al. 2019).

Phosphorus, another element in aquatic environments, exists in organic phosphate, dissolved and inorganic orthophosphate, dissolved and particulate total phosphorus, and detergent-originated polyphosphate. Orthophosphate comes from fertilizers, which are commonly measured in environmental monitoring. Organic phosphate originated from decaying plant and animal materials. The decomposition of dead plants and animals adds organic phosphorus to the water. Excess phosphates in an estuary are derived from water treatment plants, sewages, soils, agricultural fields, husbandry operations, and lawns. Phosphorus molecules attach to soil particles and are transported to the estuary along with eroded soil, especially during the rainy season when storms and torrential downpouring create strong runoff and high phosphorus loads. Upon oxygenation, phosphate forms chemical complexes with minerals such as iron, aluminum, and manganese positioned at the bottom of sediments. When the bottom part of the aquatic body becomes anaerobic, sediment-bound phosphate releases phosphate molecules back into the water. This will trigger phytoplankton blooms. Both phosphorus and nitrogen are essential nutrients for organisms involved in the aquatic food web (Steinman and Duhamel 2017; Devlin and Brodie 2023; Oduor et al. 2023; Dillon and Molot 2024; Siriwardana et al. 2024).

Phytoplankton composition and indices value

The study identified a total of 130 phytoplankton species that belong to five classes (Bacillariophyceae, Chlorophyceae, Cyanophyceae, Dynophyceae, Trebouxiophyceae) from six estuaries in Padang (Table 3). Bacillariophyceae was the richest phytoplankton class (75%), followed by Dynophyceae (18%) and Cyanophyceae (5%), while Chlorophyceae and Trebouxiophyceae only 1% (Figure 2). The dominance of Bacillariophyceae in the estuary area was previously reported in other regions, such as India (Bharathi et al. 2022), Korea (Kim et al. 2019), and America (Mancuso et al. 2021). Bacillariophyceae or diatom has been known as the most algae taxa found in marine and estuary habitats (B-Béres et al. 2023). They serve as the primary producer of the aquatic ecosystems while producing oxygen and assisting the nutrient cycle (Naselli-Flores and Padisâk 2023). Furthermore, diatom can predict weather and water conditions (Taffs et al. 2017).

Among all stations, Station 2 had the highest species number (n: 69 species), while Station 6 was the lowest (n: 38 species). Stations 1, 2, and 3 had high phytoplankton diversity (H'>3.5), while Stations 4, 5, and 6 were moderate (H' <3.1). All stations had almost equally distributed phytoplankton diversity ($0.73<E_H<0.93$); it also indicated the estuary ecosystem was in balance. The data also indicated no species dominated any studied estuary (0.03<C<0.11). All studied estuaries were lightly polluted (X: 1.00, at all stations) (Table 3). Bray-Curtis similarity analysis showed that station 5 and station 6 showed the closest similarity, followed by station 4 with station 5 and station 6 as second, station 1 and station 3 the third, and the fourth was station 2 with station 1 and station 3 (Figure 3, Table 4). Statistical analysis showed the species composition of the phytoplankton differed significantly (ANOVA $F_{5,774}$: 2.589, *p*: 0.025). However, there was no significant difference among each station using Tukey's Post Hoc test (*p*>0.05).

Knowledge of phytoplankton population dynamics is essential because temporal and spatial fluctuations in its composition may be excellent indicators for water quality (HELCOM 2024). In general, phytoplankton species undergo spatiotemporal changes in their distribution due to the different effects of hydrographical factors on individual species, and bloom dynamics are changing as a response to climate change and eutrophication, particularly in coastal areas that often experience high impact of human activities (Heiskanen et al. 2019; Saifullah et al. 2019). Therefore, there is doubt that the species composition of phytoplankton in this study varies on spatial and temporal scales.

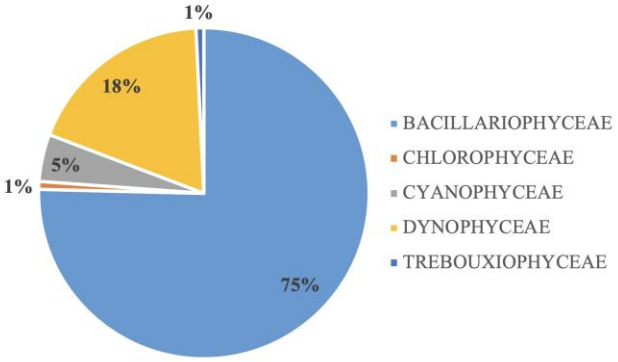

Figure 2. Percentage of phytoplankton class sampled from six estuaries in Padang City, West Sumatra, Indonesia

Table 3. Species composition and ecological indices of phytoplankton sampled from six estuaries in Padang City, West Sumatra, Indonesia

Taxa	**Station**					
	1	**2**	**3**	**4**	**5**	**6**
Bacillariophyceae						
Amphora bioculata	0	0	0	1	0	0
Amphora copulata	1	1	1	0	0	3
Amphora immarginata	2	3	1	0	0	0
Amphora lineolata	0	0	0	1	0	0
Asterionella japonica	0	1	2	0	0	0
Asteromphalus cleveanus	15	0	16	0	0	0
Asteromphalus marylandica	0	2	2	0	0	0
Bacillaria paxillifera	3	2	2	0	0	0
Bacteriastrum comosum	1	1	2	0	0	0
Bacteriastrum elongatum	0	0	0	0	3	2
Bacteriastrum hyalinum	2	3	2	6	22	6
Bacteriastrum mediterraneum	0	3	4	0	0	0
Bacteriastrum minus	3	3	2	0	0	0
Bacteriastrum varians	0	1	0	4	27	0
Biddulphia mobiliensis	0	0	0	1	0	0
Campylodiscus neofastuosus	2	8	7	0	0	0
Cerataulina bergonii	2	1	2	0	0	0
Chaetoceros affinis	14	3	2	24	28	21
Chaetoceros compressus	4	0	2	0	0	0
Chaetoceros concavicornis	5	1	4	0	0	0
Chaetoceros contortus	3	0	2	0	0	0
Chaetoceros convolutus	0	0	1	0	0	0
Chaetoceros curvisetus	0	0	0	2	2	0
Chaetoceros densus	0	0	0	0	2	4
Chaetoceros didymus	0	0	0	11	21	16
Chaetoceros diversus	15	9	12	26	31	28
Chaetoceros holsaticus	0	0	0	2	4	0
Chaetoceros lacioniosus	0	0	0	3	0	0
Chaetoceros messanensis	0	0	0	1	0	0
Chaetoceros pendulus	0	0	0	12	21	3
Chaetoceros pseudocrinitus	0	0	0	7	6	6
Chaetoceros socialis	17	12	0	135	89	84
Climacodium biconcavum	3	1	1	0	0	0
Climacodium frauenfeldianum	3	1	1	0	0	0
Climaconeis delicatula	0	1	1	0	0	0
Cocconeis placetula	3	2	1	0	0	0
Cocconeis scutellum	4	0	2	0	0	0
Cocconeis sp.	0	0	0	0	1	0
Corethron hystrix	2	1	2	0	2	0
Coscinodiscus excentricus	0	1	2	0	0	0
Coscinodiscus lineatus	0	4	1	3	3	0
Coscinodiscus radiatus	0	0	0	1	4	0
Coscinodiscus subconvacum	3	1	1	0	0	0
Cylindrotheca closterium	2	1	1	0	0	0
Dactyliosolen mediterraneus	3	3	1	0	0	0
Diploneis constrica	0	2	1	0	0	0
Diploneis gruendleri	2	0	1	0	0	0
Eucampia cornuta	0	0	0	3	0	7
Eucampia zodiatus	0	0	0	0	0	2
Frustulia rhomboides	4	1	1	0	0	0
Frustulia vulgaris	0	4	3	0	0	0
Gomphonema gracile	1	4	1	0	0	0
Grammatophora oceanica	0	3	1	0	0	0
Guinardia flaccida	0	0	0	3	7	0
Guinardia striata	0	3	2	0	0	0
Hemiaulis hauckii	0	0	0	0	0	2
Hemiaulus membranaceus	0	0	0	1	4	0
Leptocylindrus danicus	0	0	0	0	2	2
Leptocylindrus minimus	0	0	0	2	0	5
Licmophora abbreviata	2	4	4	0	0	0
Licmophora ehrenbergii	0	1	0	0	0	0
Lioloma pacificum	1	3	2	1	0	3
Melosira nummuloides	3	0	1	0	0	0
Meuniera membranacea	0	2	2	0	0	0
Navicula anglica	0	0	0	2	0	0
Navicula directa	4	2	2	1	0	0
Navicula lanceolata	0	1	2	0	0	0
Navicula membranacea	0	0	0	1	0	0
Navicula salinarum	5	1	2	0	0	0
Navicula transitans	0	0	0	3	0	0
Nitzschia clausii	0	1	0	0	0	0
Nitzschia longissima	0	0	0	7	4	4
Nitzschia pacifica	3	1	1	0	0	0
Nitzschia pungens	0	0	0	21	21	15
Nitzschia sigma	5	1	0	0	0	0
Nitzschia vitrea	0	2	2	0	0	0
Pinnularia viridis	4	1	0	0	0	0
Pinnunavis elegans	1	2	3	0	0	0
Planktoniella sol	0	0	0	1	0	0
Pleurosigma directum	0	0	0	1	0	0
Pleurosigma normanii	0	0	0	1	0	0
Pseudo-nitzschia delicatissima	1	3	0	0	0	0
Pseudo-nitzschia seriata	4	3	4	28	27	26
Rhizosolenia alata	0	0	0	3	0	2
Rhizosolenia fragilissima	0	0	0	2	2	0
Rhizosolenia hebetata	0	0	0	0	2	0
Rhizosolenia setigera	0	0	0	3	3	6
Rhizosolenia stolterforthii	0	0	0	3	7	11
Rhopalodia gibberula	0	0	0	2	0	0
Skeletonema costatum	0	0	0	21	2	6
Stephanopyxis palmeriana	3	2	2	0	0	0
Synedra acus	0	0	0	1	0	0
Synedropsis hyperborea	2	0	2	2	0	0
Tabularia fasciculata	0	0	0	1	0	0
Thalassionema nitzschioides	0	0	0	3	7	11
Thalassiosira baltica	0	0	0	2	3	2
Thalassiosira punctigera	0	0	0	1	0	0
Thalassiothrix frauenfeldii	0	0	0	4	0	7
Chlorophyceae						
Coelastrum indicum	0	0	0	1	0	0
Cyanophyceae						
Anabaena catenula	0	3	1	0	0	0
Anabaena sphaerica	3	1	1	0	0	0
Microcystis smithii		0	0	0	0	1
Oscillatoria margaritifera	3	1	1	0	0	0
Richelia intracellularis		2	0	0	0	0
Trichodesmium erythaeum	3	1	2	0	1	0
Dynophyceae						
Alexandrium sp.	0	0	4	1	0	0
Blixaea quinquecornis	4	7	2	2	0	0
Dinophysis caudata	2	5	1	2	2	0
Diplopsalopsis asymmetrica	3	1	2	0	0	0
Gonyaulax spinifera	2	0	2	0	0	0
Gonyaulax sp.	2	0	2	2	1	1
Peridinium willei	5	0	6	0	0	0
Peridinium sp.	0	0	0	1	0	0
Prorocentrum asymmetrica	0	1	1	0	0	0
Prorocentrum divergens	0	0	0	3	18	4
Prorocentrum gracile	0	0	0	13	15	11
Prorocentrum micans	1	1	1	36	36	14
Prorocentrum rhathymum	1	1	1	0	0	1
Protoperidinium abei	0	3	1	0	0	0
Protoperidinium brevipes	0	0	0	1	3	5
Protoperidinium conicum	2	1	0	4	0	0
Protoperidinium pellucidum	2	1	1	6	14	12
Protoperidinium subpyriforme	0	4	0	1	0	1
Scrippsiella acuminata	0	11	0	27	5	0
Tripos fusus	0	3	0	0	0	1
Tripos furca	1	4	2	1	1	1
Tripos kofoidii	0	1	1	0	0	0
Tripos muelleri	0	2	0	0	1	0
Tripos trichoceros	0	1	1	1	0	1
Trebouxiophyceae						
Chodatella sp.	0	0	0	4	0	0
Total (N)	191	172	152	470	454	337
Number of species (n)	53	69	68	62	40	38
Shannon-Wiener index (H’)	3.65	3.93	3.89	3.02	3.02	2.95
Equitability index (E_H)	0.92	0.93	0.92	0.73	0.82	0.81
Dominance index (C)	0.04	0.03	0.03	0.11	0.07	0.09
Saprobic index (X)	1	1	1	1	1	1

Table 4. Bray-Curtis similarity matrix showing the similarity of phytoplankton among six observed stations

Station	1	2	3	4	5	6
1	1.00	0.51	0.6	0.19	0.18	0.16
2	0.51	1.00	0.53	0.2	0.18	0.16
3	0.6	0.53	1.00	0.18	0.17	0.16
4	0.19	0.2	0.8	1.00	0.69	0.70
5	0.18	0.18	0.17	0.69	1.00	0.72
6	0.16	0.16	0.16	0.70	0.72	1.00

Table 5. Potential Harmful Phytoplankton identified from six estuaries in Padang City, West Sumatra, Indonesia. The symbol (+) indicates the presence of algae species, and (-) indicates absence.

Species	Station					
	1	2	3	4	5	6
Alexandrium sp.	-	-	+	+	-	-
Amphora spp.	+	+	+	+	-	+
Blixaea quinquecornis	+	+	+	+	-	-
Chaetoceros convolutes	-	-	+	-	-	-
Cylindrotheca closterium	+	+	+	-	-	-
Dinophysis caudata	+	+	+	+	+	-
Gonyaulax spp.	+	-	+	+	+	+
Prorocentrum spp.	+	+	+	+	+	+
Protoperidinium subpyriforme	-	+	-	+	-	+
Pseudo-nitzschia delicatissima	+	+	+	+	+	-
Pseudo-nitzschia seriata	+	+	-	-	+	+
Scrippsiella acuminata	-	+	-	+	+	-
Tripos furca	+	+	+	+	+	+
Tripos fusus	-	+	-	-	-	+
Tripos muelleria	-	+	-	-	+	-
Tripos trichoceros	-	+	+	+	-	+

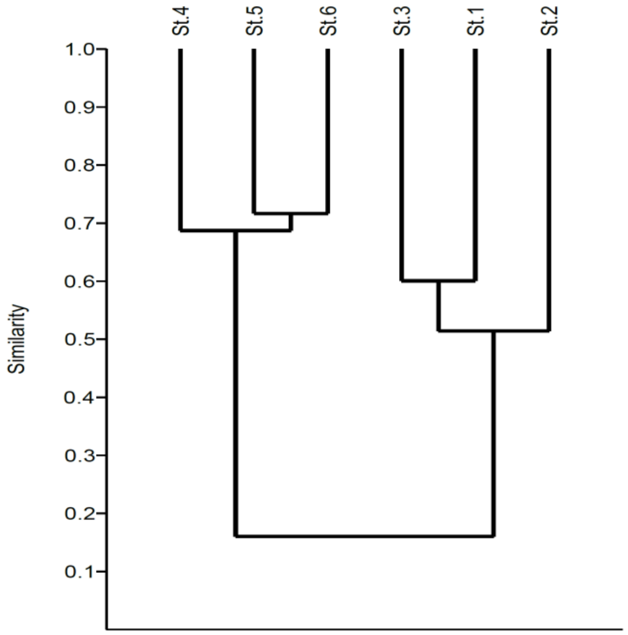

Figure 3. Dendrogram clustering represents the Bray-Curtis similarity of the phytoplankton sampled from six estuaries in Padang City, West Sumatra, Indonesia

Most rivers in Padang, such as Batang Kandis, Batang Air Dingin, Batang Kuranji, and Batang Arau, have been previously reported to be polluted (Dewata 2019). Batang Kuranji and Batang Arau were the most affected (Dewata 2019; Chaniago 2022). These rivers are polluted mainly by domestic and household effluents in the form of plastics, chemical and physical. The community seemed to be the least concerned about managing their waste before discarding it to the environment, disobeying municipal rules and laws regarding environmental health (Chaniago 2022). Flowing water is naturally able to clean itself and regenerate its ecosystem whenever polluted. Self-purification is an ability possessed by natural landscapes such as rivers, especially using their flows and periodical enrichment from the decomposition of organic material. Some physical processes, i.e., dilution, sedimentation, filtering, and aeration, along with chemical processes, i.e., oxidation and reduction, as well as biological processes of mineralization and assimilation, all contribute to the self-purification ability of rivers (Mishra and Saxena 2024).

Potential harmful phytoplankton

Sixteen phytoplankton species identified in this study were assessed to be potentially harmful in aquatic environments. Some are known as poisonous species that could kill fish, such as *Alexandrium*, *Dinophysis*, *Prorocentrum*, and *Pseudo-nitzschia*. The number of species of the potential HABs from station 1 to station 6 is 9, 13, 11, 11, 8, and 8, respectively, where Batang Arau estuaries have the highest potential HAB species. *Prorocentrum* spp. and *Tripos furca* can be found at all estuaries. In comparison, *Amphora* spp., *Dinophysis caudata*, *Gonyaulax* spp., and *Pseudo-nitzschia delicatissima* were observed at 5 estuaries, and the rest were at 1 to 4 stations (Table 5).

Alexandrium is one of the common algae in the class Dinophyceae. It is well known as one of the causes of Harmful Algal Blooms (HABs) phenomena due to producing toxin compounds and bringing negative impact or damage to other marine organisms, aquaculture, fishery, tourism, as well as inducing human intoxications and even death after consumption of contaminated shellfish or fish (Montuori et al. 2024). Similarly, *Blixaea quinquecornis* (Dinophyceae member) and *Pseudo-nitzschia* spp. are also considered harmful algal bloom species (Romero et al. 2022; Schreiber et al. 2023). In general, the Harmful Algal Blooms (HABs) species from the group of Dinophyceae or Bacillaryophyceae are toxic to other aquatic species due to the occurrence of toxin compounds such as domoic acid, saxitoxin, brevetoxin, okadaic acid, pectenotoxin-2 and ciguatoxin that cause damages or negative effects such as Ciguatera Fish Poisoning (CFP), Amnesic Shellfish Poisoning (ASP), Diarrheic Shellfish Poisoning (DSP), and Paralytic Shellfish Poisoning (PSP) (Lopes et al. 2019; Young et al. 2020; Pease et al. 2022; Pradhan et al. 2022; Oh et al. 2023). Environmental variables also play a crucial role in the blooming of this algae, such as sea surface temperature and high salinity. Indonesia, as a tropical country, has been considered to have a high temperature and also high salinity. Therefore, the occurrence of the

HAB species in another region from this country cannot be avoided (Mahmudi et al. 2020; Tambaru et al. 2021; Hasani et al. 2022). In addition, abiotic factors or nutrient enrichment in the water body, such as nitrogen and phosphate, also affect the blooming of the potentially harmful algae (Davidson et al. 2014; Aryawati et al. 2016; Mahmudi et al. 2020). The overall result of this study ushers further action to alleviate the pollution in the estuaries and connected rivers, especially from the effluent originating from households or industries.

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