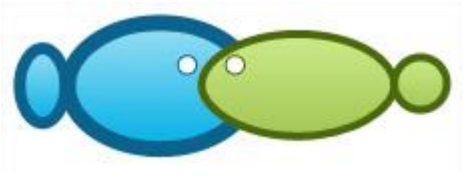

Phytoplankton chlorophyll-a content and its relationship with water quality in the Gulf of Kabung and small islands, Padang City, Indonesia

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Abstract. Investigations of phytoplankton chlorophyll-a and water variables are important to determine the environmental conditions in a certain area. The phytoplankton biomass always fluctuates and is affected by many factors, such as nutrient inputs, anthropogenic matter and seasonal monsoon. This study aimed to investigate the chlorophyll-a concentration and its relationship with the water variables at the west coast of Padang waters, Indonesia, from December 2020 to July 2021, in 8 stations with 3 sites each. The chlorophyll-a concentration and its distribution were assessed using a spectrophotometric method and a QGIS heatmap. Results showed that chlorophyll-a concentration was low, with no significant difference ($p>0.05$) among all 8 stations. The mean value ranged from 0.002 to 0.09 mg m^{-3}, with the highest value in the coastal area (0.0438 0.022 mg m^{-3}) and lowest at Sikuai island (0.0042±0.0008 mg m^{-3}). The water variables showed a minor variation, except for transparency and total suspended solids (TSS). There was no correlation between the chlorophyll-a content and water variables. Overall, the water variables are in a normal condition for phytoplankton in Padang waters.
Key Words: chlorophyll-a concentration, Gulf of Kabung coastline, Sikuai island, water clarity, TSS.

Introduction. The group of phytoplankton is considered one of the main biotic components that determine the energy flow from the lower to the higher trophic components through the food chain (Bellinger & Sigee 2015). Most of the plankton is distributed in marine and estuarine ecosystems (de Vargas et al 2015; Lestari et al 2021; Singh et al 2022), and performs a significant role in the ecosystems by photosynthesis (Yang et al 2020). Availability of nutrients in any ecosystem may enhance the phytoplankton growth, which ultimately supports consumer organisms of different trophic levels, for instance, herbivorous zooplankton, forming a strong link within food chain components, and participating in the complexity of the food web (Reynolds 2006).

Phytoplankton biomass is commonly used as a parameter of algal abundance and is an essential parameter for water quality as it can be a bio-indicator in determining the level of eutrophication (Zheng & DiGiacomo 2017; Poddar et al 2019). Human activities may increase organic matter levels and eutrophication, causing algae blooms and low dissolved oxygen in the waters (Retnaningdyah et al 2019). According to Gupta (2014), the chlorophyll-a concentration can be an indicator of the level of eutrophication and of the availability of nutrients in waters. Consequently, it is used as a measuring tool for water quality (Boyer et al 2009). The concentration of chlorophyll-a in waters describes the effects of various factors, some of which being human activities (Li & Liu 2019).

Because of the importance of chlorophyll-a in the ecosystem, several studies have been conducted to measure the chlorophyll-a concentration in the phytoplankton, from traditional methods (such as colorimetric, spectrophotometric, fluorescence and chromatography paper) (Yentsch & Menzel 1963; Riyono 2006; Protopopov et al 2021) to modern technology (such as remote sensing or Landsat image) (Zheng & DiGiacomo 2017; Poddar et al 2019; Pirasteh et al 2020).

The west coast of the Padang City, West Sumatra, Indonesia, is one of the coastal area that face the Indian Ocean directly. This location is comprised of a complex ecosystem, with an estuary, coastal area and several small islands that provide a

complex biodiversity. Studies on phytoplankton communities and chlorophyll-a have been carried out at the west coast of the Padang City (Susanti 2012; Fitra 2013; Fitra et al 2013; Arta et al 2016; Merina 2016; Merina et al 2016). These studies showed a high fluctuation in the chlorophyll-a concentration in the Padang waters. Interestingly, in 2019, there was a blooming algae phenomenon in the coastal area of Padang city. This was due to the accumulation of organic and non-organic materials or nutrients (such as nitrogen, phosphorus, and silicate, some from anthropogenic waste) in the river flowing to the estuary and sea waters. Therefore, this phenomenon cannot be avoided (Pelly et al 2020). Since the blooming, there has been a lack of information about the phytoplankton condition in the coastal area of Padang City. Continuous research on the phytoplankton, especially its chlorophyll concentration is needed to provide information about the water quality that may affect the communities in the area. Therefore, this study was carried out to investigate and update the information about the chlorophyll-a concentration and its relationship with the water variables in the Gulf of Kabung and small islands waters, around the west coast of Padang City, West Sumatra, Indonesia.

Material and Method

Field works. Sampling was carried out from December 2020 to July 2021 at 8 stations; one station in the Gulf of Kabung coastline and seven stations in the seven small islands, including Setan island (station 2), Pasumpahan island (station 3), Sikuai island (station 4), Sirandah island (station 5), Sironjong island (station 6), Bintangor island (station 7) and Sinyaru island (station 8) (Figure 1).

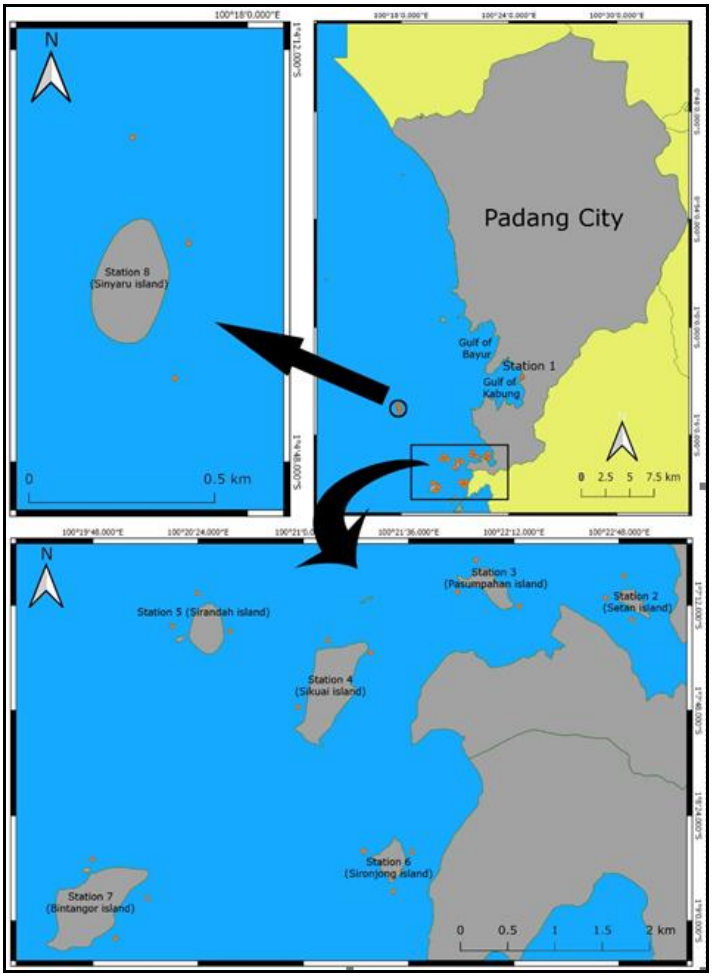

Figure 1. 8 sampling stations with 3 sites (orange dots) of the chlorophyll-a distribution in the Gulf of Kabung and small islands, Padang city, West Sumatra, Indonesia.

In each station, 20 mL of the seawater were sampled. All of the samples were labelled and stored in a cool box temporarily and transported from the field to the Laboratory of Plant Physiology, Department of Biology, Faculty of Mathematics and Natural Sciences, Andalas University, Padang, for further analysis. During sampling, several water variables were measured, such as surface temperature, salinity, pH, water clarity and dissolved oxygen (DO). Meanwhile Nitrite (NO_2), nitrate (NO_3), ammonia (NH_3), phosphate (PO_4) and total suspended solids (TSS) were measured in the laboratory. Temperature and pH were measured with an Adwa instrument (AD12), salinity with a hand refractometer, water clarity with a Sechhi disk and DO with Winkler's method. NO_2, NO_3, NH_3 and PO_4 were measured with a spectrophotometer UV-VIS Simadzu 1200 and TSS with the gravimetric method.

Laboratory works. The concentration of chlorophyll-a (Chl-a) in the phytoplankton was measured using the spectrometric method. At first, 20 mL of each water sample were filtered using a cellulose paper filter sized 0.45 µm using of a vacuum pump. The suspended solids and the filter paper were extracted using 90% acetone and ground until dissolved. The samples were incubated at 4°C for 16 hours. The samples were then placed into a centrifuge and rotated at 4000 rpm for 10 min. The extracts were analyzed using a spectrophotometer Thermo Spectronic 20+ 2017, at trichromatic wavelengths (664, 648 and 630 nm). The concentration of Chl-a was calculated using the APHA (2005) standard, with formula as follows:

$$\text{Chl-a} = 11.85\ (\lambda 664) - 1.54(\lambda 648) - 0.008(\lambda 630) \times \frac{v}{V}$$

Where: Chl-a is chlorophyll-a, λ664, λ645 and λ630 are the reading results of the absorbance value at that wavelength; v is the volume of the extract (mg); V is the volume of the sample (m^3).

Data analysis. The water variables (surface temperature, salinity, pH, water clarity, DO, TSS, NO_2, NO_3, NH_3 and PO_4) were analyzed descriptively and a Principal Component Analysis (PCA) was performed in Past v. 3.22 software to determine the differences of the water variables within each station. Significant differences in the mean of the chlorophyll-a concentration from each station were determined with a one-way ANOVA test. The relationship between the chlorophyll-a concentration and water variables was analyzed using multiple linear regression. All datasets were first tested for normality and homoscedasticity. If data failed the tests, they were logarithmically transformed [log(x+1)] or arcsine-transformed (for proportions) as required for the parametric analysis (Sokal & Rohlf 2012). Levels of significance were tested at $p<0.05$. All data were calculated using SPSS v. 23 software package. Chl-a concentrations data were plotted as a heat map using QGIS v. 3.10 software (QGIS Development Team 2014), where the value changes linearly based on the distance to the nearest sample and is not affected by the location of the sample data (Achilleos 2011). This distribution pattern visually and informatively describes the distribution of chl-a for each station.

Results. Measurements of water quality parameters showed that the surface temperature ranged from 27-33°C, salinity ranged from 29-37‰, pH ranged from 7-7.35, water clarity ranged from 1.5-21 m, DO ranged from 7.5-12.43 mg L^{-1}, phosphate ranged from 0.001-0.028 mg L^{-1}, nitrate and nitrite were below 0.001 mg L^{-1} and TSS ranged from 0.07-0.33 mg L^{-1}. Detailed results of the water parameters values are presented in Figure 2 and Table 1. PCA showed that temperature, NO_2 and TSS strong-positively affected the condition of the coastal zone (station 1). On the other hand, NO_3, DO and PO_4 strong-negatively affected the condition of Sironjong, Setan and Pasumpahan islands in the axis 1 (Figure 3).

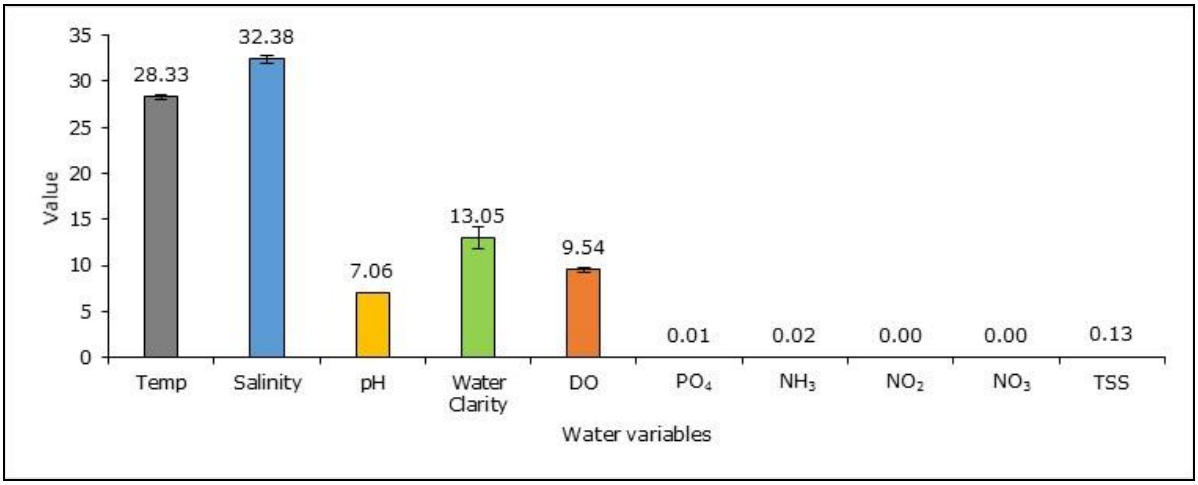

Figure 2. The mean value (±SE) of water parameters: temperature, salinity, pH, water clarity, dissolved oxygen (DO), phosphate (PO_4), ammonia (NH_3), nitrite (NO_2), nitrate (NO_3) and total suspended solids (TSS) in the west coast of Padang City, West Sumatra, Indonesia.

Table 1

Mean (±SE) of each water variables measured from 8 stations in the west coast of Padang City, West Sumatra, Indonesia

Water variables	*Sampling localities*							
	Islands							
	Coastal area	*Setan*	*Pasumpahan*	*Sikuai*	*Sirandah*	*Sironjong*	*Bintangor*	*Sinyaru*
Temperature (°C)	29.33 ±1.86	28	28.33 ±0.33	28.67 ±0.33	27.67 ±0.67	28.67 ±0.33	27.67 ±0.33	28.33 ±0.33
Salinity (°/₀₀)	31.33 ±1.86	30.67 ±0.33	32.33 ±0.33	31.67 ±0.33	33	31.67 ±0.33	33.33 ±0.33	35 ±1
pH	7	7.003 ±0.003	7.09 ±0.07	7.01 ±0.01	7.06 ±0.02	7.01 ±0.006	7.12 ±0.05	7.23 ±0.11
Water clarity (m)	17.33 ±0.14	10 ±0.58	10	140 ±1	16	14.33 ±0.33	17.33 ±0.67	21
DO (ppm)	10.08 ±1.21	9.72 ±1.12	8.99 ±0.86	8.33 ±0.32	8.2 ±0.24	10.66 ±0.76	11.29 ±0.59	9.03 ±0.36
Phosphate (mg L^{-1})	0.007 ±0.003	0.01 ±0.01	0.01 ±0.01	0.004 ±0.003	0.001	0.001	0.001	0.005 ±0.004
Ammonia (mg L^{-1})	0.001	0.08 ±0.06	0.001	0.02 ±0.01	0.03 ±0.01	0.03 ±0.01	0.001	0.001
Nitrate (mg L^{-1})	0	0	0	0	0	0	0	0
Nitrite (mg L^{-1})	0	0	0	0	0	0	0	0
TSS (mg L^{-1})	0.22 ±0.06	0.1	0.11 ±0.01	0.12 ±0.02	0.11	0.17 ±0.01	0.09 ±0.01	0.13 ±0.02

Note: DO - dissolved oxygen; TSS - total suspended solids.

The concentration of chl-a in this study showed a high fluctuation in spatial scale. The lowest chl-a was found in the Sikuai island (station 4) with a mean of 0.0042±0.0008 mg m^{-3}, while the highest was found in the Gulf of Kabung coastline (station 1) with a mean of 0.0438±0.022 mg m^{-3}, although there was no significant difference in the chl-a concentration ($p>0.05$). Multiple linear regression between the chl-a concentration and the water parameters values showed that there was no significant relationship differences among them ($p>0.05$). Detailed results on chl-a concentration and its distribution are presented in Figures 4 and 5.

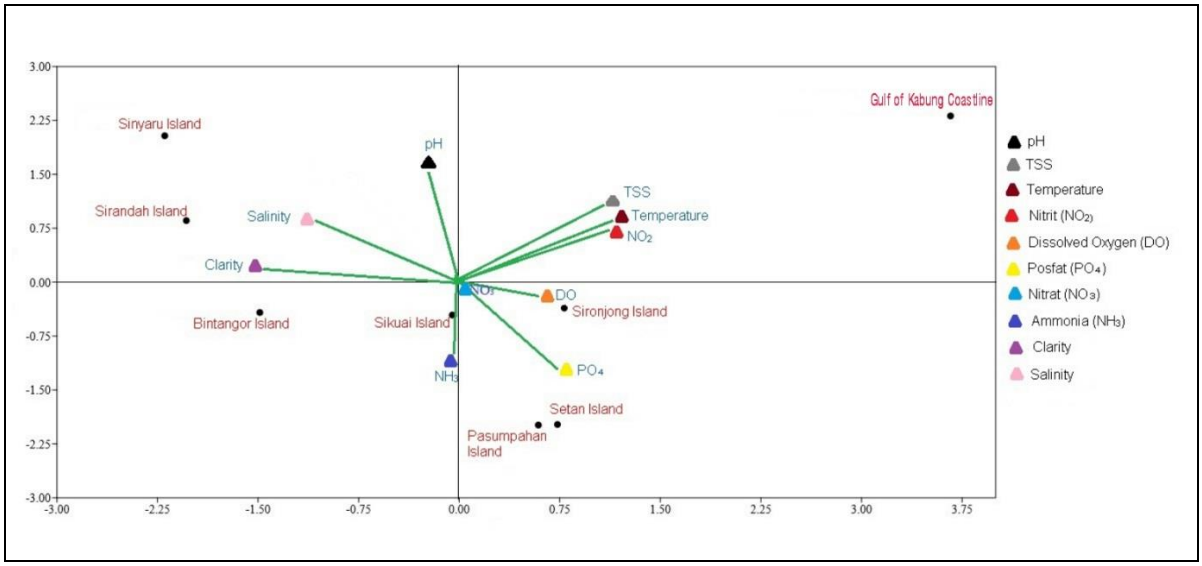

Figure 3. Principal Component Analysis (PCA) ordination diagram for the water parameters: temperature, salinity, pH, water clarity, dissolved oxygen (DO), total suspended solids (TSS), nitrite (NO_2), nitrate (NO_3), ammonia (NH_3) and phosphate (PO_4), with the sampling stations in the west coast of Padang City, West Sumatra, Indonesia.

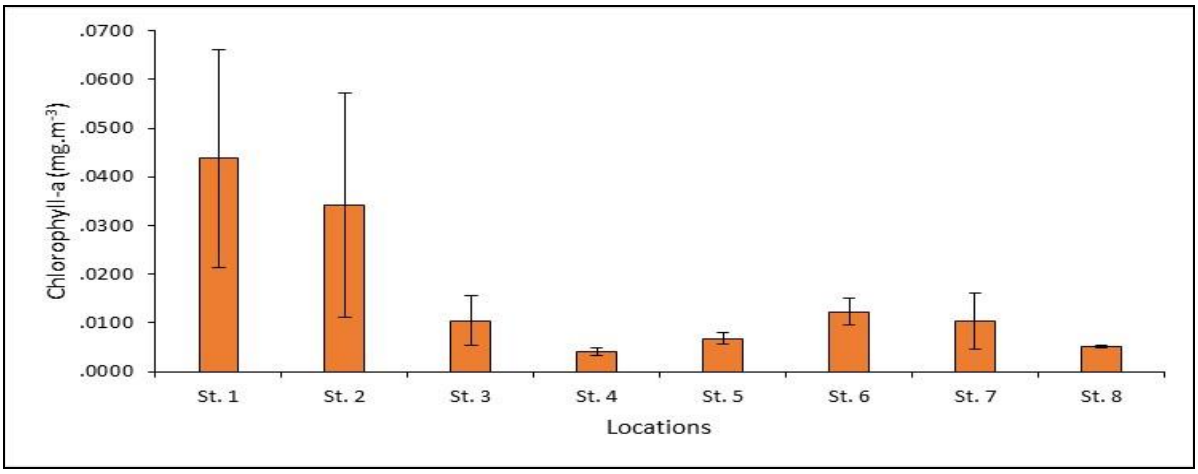

Figure 4. Mean (±SE) value of the chlorophyll- a from the west coast of Padang City, West Sumatra, Indonesia; St. 1 - Gulf of Kabung coastline; St. 2 - Setan island; St. 3 - Pasumpahan island; St. 4 - Sikuai island; St. 5 - Sirandah island; St. 6 - Sironjong island; St. 7 - Bintangor island; St. 8 - Sinyaru island.

Figure 5. Distribution of chlorophyll-a from 8 stations during this study in the west coast of Padang City, West Sumatra, Indonesia.

Discussion. Although there was no correlation between the water variables and the chl-a distribution in this study, the condition of the water variables are very important to determine the concentration and also the biomass of chl-a. Our results showed that the variations in water parameters values (surface temperature, salinity, pH, DO, NO_2, NO_3, NH_3, PO_4) are minor, except for the water clarity and TSS. Sea surface temperature in Indonesia typically ranges from just over 25°C to just below 30°C (Tomascik et al 1997). This condition is suitable for chl-a, but higher temperatures may decrease the chl-a concentration (Nurdin et al 2013).

Salinity at sea surface resembles the evaporation–precipitation pattern, with some differences due to runoff, ocean currents and ice melt. The salinity range in the open ocean is around 30-40‰. While salinity in coastal estuaries can be much lower, it does not affect large oceanic-scale patterns (Talley 2002). In Indonesia, the salinity of the ocean ranges between 31.5 and 34.5 ‰. It is highest at depths of 80-200 m, within the thermocline. The waters associated with the Indonesian throughflow have monsoonal variations (Tomascik et al 1997). Sometimes, the salinity positively or negatively affects chl-a concentration (Garcia-Eidell et al 2021).

The pH and DO also determine the chl-a concentration in the water (Jamshidi et al 2009; McCluskey et al 2022). In Indonesia, the mean of seawater pH ranges from 7.7 to 8.2 (Rizki et al 2015). This pH range is positively correlated with chl-a concentration (Zang et al 2011). The DO content in the water ranges from 6 to 14 mg L^{-1} (Connell & Miller 1984). Zang et al (2011) also reported that DO between 7-10 mg L^{-1} increases the chl-a concentration in the water. NO_2, NO_3 and NH_3 in the water influence the photosynthesis of phytoplankton (Grant et al 1972). Nitrite reduction in the light is very closely coupled to the photosynthetic electron transport system, whereas nitrate is not reduced photosynthetically *in vivo* (Kessler & Zumft 1973). Sometimes, the concentration of NO_2, NO_3 and NH_3 also positively affect the chl-a concentration (Elser et al 1990; Bbalali et al 2013).

Redfield (1958) expressed that phosphorus is a key limiting nutrient in marine systems. P controls phytoplankton biomass in numerous freshwater systems. P availability is growth-limiting in certain marine systems and can impact algal species composition (Lin et al 2016). Physiological condition and the needs of nutrient by phytoplankton also depend on the P condition (Hecky & Kilham 1988).

Following Ryther & Dunstan (1971), nitrogen is generally seen as the limiting nutrient in coastal systems and has received the bulk of research interest. Meeuwig et al (1998) illustrated that the relation between chl-a and total nitrogen (TN) is marginally stronger than that between chl-a and total phosphorus (TP), suggesting that TN, rather than TP, limits estuarine chl-a.

Water clarity is greatly influenced by phytoplankton abundance and should differ greatly in spatial and temporal scales. Chl-a is a photosynthetic pigment found in all photosynthetic organisms, including all algae, making it an excellent proxy for determining algal biomass (Wetzel 2001). An increase in algae influences water depth clarity (Hoyer et al 2002; Swift et al 2006; Mamun et al 2020).

TSS is one of the main indicators of sediment in waters. During the wet season, high rainfall and increased surface runoff caused an increase in the water turbidity and a decrease in water transparency, resulting in a reduction in light intensity and algal density, noted that suspended sediments reduced light penetration and caused a decline in algal growth (Hilaluddin et al 2020) as well as the chl-a concentration (Gallegos & Moore 2000

Our results showed that overall chl-a concentrations were relatively low, with a total mean of 0.02±0.004 mg m^{-3} in the west coast of Padang City, with the highest value occurring at the coastal area. Previous works in this location also showed that the mean chl-a concentration varied from 0.02-0.91 mg m^{-3} and the coastal zone is more rich in chl-a (Fitra et al 2013; Arta et al 2016; Merina et al 2016; Pelly et al 2020). Comparison of the water variables and chl-a concentration in Padang City from several works is presented in Table 2. According to Gin et al (2000), the high concentration of chl-a in the coastal area is due to the location being protected compared to the open oceans. Furthermore, the accumulation of organic matter and nutrients may affect the phytoplankton and chl-a concentration (Wetzel 2001; Pelly et al 2020). On the other hand, water current will mix organic matter and other materials in the open ocean, making the chl-a concentration mostly constant and lower compared to the coastal area (Gin et al 2000; Webb 2019).

Table 2

Comparison of water parameter values and chlorophyll-a concentration in Padang waters, West Sumatra, Indonesia

Value	*Temp (°C)*	*Sal (°/₀₀)*	*pH*	*Clarity (m)*	*DO (ppm)*	*PO_4 (mg L^{-1})*	*NH_3 (mg L^{-1})*	*NO_2 (mg L^{-1})*	*NO_3 (mg L^{-1})*	*TSS (mg L^{-1})*	*Chl-a (mg m^{-3})*	*Sources*
Minimum	30	9	6	2	2.63	0.05	0.02	0.04	0.02	n/a	0.07	
Maximum	32	35	7	12	4.45	0.08	0.04	0.07	0.25	n/a	0.66	Fitra et
Mean	31.17	26.5	6.83	5	3.35	0.06	0.03	0.04	0.14	n/a	0.3	al (2013)
St. error	0.31	4.05	0.17	1.51	0.25	0	0	0	0.04	n/a	0.09	
Minimum	30	28	7	1.5	n/a	n/a	n/a	n/a	n/a	n/a	0.47	
Maximum	31	31	7	4.5	n/a	n/a	n/a	n/a	n/a	n/a	1.43	Arta et al
Mean	30.5	29.5	7	2.88	n/a	n/a	n/a	n/a	n/a	n/a	0.91	(2016)
St. error	0.29	0.65	0	0.65	n/a	n/a	n/a	n/a	n/a	n/a	0.2	
Minimum	30	31	8.68	3	4.42	0.02	n/a	n/a	0.01	50	0.01	
Maximum	31	32	8.83	6	6.66	0.03	n/a	n/a	0.025	150	0.025	Merina et
Mean	30.33	31.67	8.76	4.67	5.8	0.03	n/a	n/a	0.02	100	0.02	al (2016)
St. error	0.21	0.21	0.03	0.49	0.39	0	n/a	n/a	0	15.28	0	
Minimum	18.25	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.001	
Maximum	29	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	23.29	Pelly et
Mean	~30	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.82	al (2020)
St. error	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.11	
Minimum	27	29	7	1.5	7.5	0.001	0.001	<0.001	<0.001	0.07	0.002	
Maximum	33	37	7.35	21	12.43	0.03	0.21	<0.001	<0.001	0.33	0.09	Current
Mean	28.33	32.37	7.06	13.05	9.54	0.005	0.02	<0.001	<0.001	0.13	0.02	study
St. error	0.24	0.35	0.21	1.15	0.31	0.002	0.01	<0.001	<0.001	0.01	0.004	

Note: Temp - temperature; Sal - salinity; DO - dissolved oxygen; TSS - total suspended solids; Chl-a - chlorophyll a; n/a - non-available data.

Conclusions. The concentration of chlorophyll-a has a low value in Padang City. The highest concentration is found in the coastal area. The variation of the water parameters values in this study is minor (except for water clarity and TSS), and almost similar to previous works. However, there was no significant correlation between the chlorophyll-a concentration and water variables. The coastal area is rich in organic matter and nutrients that are needed by phytoplankton. Therefore, chlorophyll-a values are always higher in the coastal area compared to the separate islands or open ocean.

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Conflict of Interest. The authors declare that there is no conflict of interest.

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