Assessment of pollution status of tropical coastal lakes using modified Water Quality Index (WQI) based on physio-chemical parameters

[1]Ahmad Muhtadi, [2]Fredinan Yulianda, [2]Mennofatria Boer, [2]Majariana Krisanti, [2]Etty Riani, [1]Rusdi Leidonald, [3]Qadar Hasani, [4]Muhammad R. Cordova

[1] Department of Aquatic Resources Management, Faculty of Agriculture, Universitas Sumatera Utara, Indonesia; [2] Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, IPB University, Indonesia; [3] Department of Aquatic Resources, Faculty of Agriculture, Lampung University, Indonesia; [4] Research Center for Oceanography, Earth Sciences Research Organizations, National Research and Innovation Agency (BRIN), Jakarta, Indonesia. Corresponding author: A. Muhtadi, ahmad.muhtadi@usu.ac.id

Abstract. The water quality index (WQI) is a widely used metric for assessing the quality of water. However, the current WQI is primarily used for freshwater, and no particular study has been conducted for estuarine waters, particularly for tidal lakes (or coastal lakes). In this study, the Siombak Water Quality Index (SWQI) is a composite of the characteristics of tide-influenced lake waters and estuaries, and it was developed by following 4 steps: 1) selection of key parameters that were adjusted to the characteristics of Lake Siombak waters, 2) determination of weight (wi) in order to ascertain the relative importance (influence) of parameters in determining the water quality via PCA, 3) determination of sub-index values, and 4) determination of the aggregate index. In Lake Siombak, 14 physical and chemical parameters were selected and measured throughout the year. Organic matter, dissolved and suspended matter, phosphate, and discharge are the most significant variables in Lake Siombak, both at high and low tides. As a result, Lake Siombak's primary pollutants are organic matter, suspended matter, and nutrients. According to the SWQI analysis, the water quality in Lake Siombak is better at high tide than at low tide. Water conditions are worse during the dry season (February-August) than during the rainy season (Septrmber-January).

Key Words: coastal lagoon, estuarine, PCA, water quality, Siombak Water Quality Index (SWQI).

Introduction. The water quality index (WQI) is a widely used metric for assessing the quality of water (Sutadian et al 2016, 2018; Quevedo-Castro et al 2018; Li et al 2019; Ma et al 2020). Typically, WQI considers generic water quality parameters, such as dissolved oxygen, pH, temperature, and total dissolved solids (Ott 1978; Gupta et al 2003). Sutadian et al (2018) considered this method to be the most straightforward and most promising, and it is constantly being improved and developed by various institutions and researchers (Li et al 2019). Sutadian et al (2018), Li et al (2019), and Ma et al (2020) considered the distribution characteristics of basic and additional parameters for each region to obtain more accurate and precise evaluation results.

The current WQI is primarily a surface freshwater allotment developed in subtropical regions, such as the NSF-WQI and CCME (Ott 1978; CCME 2017). In other tropical freshwaters, the Malaysian water quality index is used (DoE 2012; 2017), and in Indonesia, a Stored Method and a Pollution Index are used (MoE 2003). The Malaysian marine water quality index (DoE 2017) is available for coastal waters and estuaries, but not for Indonesian waters because it is specifically for marine waters not for estuaries. Additionally, several researchers have developed indexes for estuarine: the water quality index for estuarine water quality management in South Africa (Wepener et al 2006), the coastal water pollution index (CWPI) (Panda & Pattnayak 2013), the water quality index of the estuarine environment (Ramasamy et al 2015), and the Chinese estuarine water quality index (Li et al 2019), but also the coastal water quality index (for seagrass and coral) which also applies to marine waters (Nguyen & Sevando 2019).

Lobato et al (2015) and Quevedo-Castro et al (2018) developed a new WQI that takes the hydrological cycle into account when evaluating water quality in reservoir areas. Bassi & Kumar (2017) used the WQI as a tool for wetland restoration. Kangabam et al (2017) developed a WQI for a specific lake, whereas Sim & Tai (2018) and Sutadian et al (2018) developed WQI for tropical rivers in Malaysia and West Java, Indonesia. Finally, Li et al (2019), Nguyen & Sevando (2019) and Ma et al (2020) developed estuarine and coastal waters indices. However, there is no arrangement in place for the waters of tidal lakes or coastal lakes. As such, the study compiles and develops a new index for tropical tidal lake waters, as a first step toward evaluating the quality of coastal lake water, particularly of tropical tidal lake water.

Lake Siombak is critical to the lake ecosystem because it serves as a catchment area for local fishers and a tourist destination for residents of Medan and the surrounding areas (Muhtadi et al 2016). Nowadays, the city of Medan's growing population exacerbates the problem of environmental degradation and water pollution, including lakes. Lake water input from the heavily polluted Belawan waters (Indirawati 2017) and the potential pollution from the adjacent Terjun landfills have contaminated the waters of the Lake Siombak (Muhtadi et al 2016). As a result, it is necessary to evaluate water quality to establish the most appropriate policy for the use and management of water resources (Wu et al 2017). Thus, water quality monitoring is critical for the Lake Siombak ecosystem's sustainability. The aim of the study was to determine the level of pollution in the waters of Siombak Lake based on the water quality index which has been modified according to the characteristics of the tidal lake waters.

Material and Method

Description of the study sites. Lake Siombak is an open lake with waters influenced by tides from the sea (Belawan) up to a distance of 7 km. Lake Siombak covers an area of 28.5 ha (Figure 1).

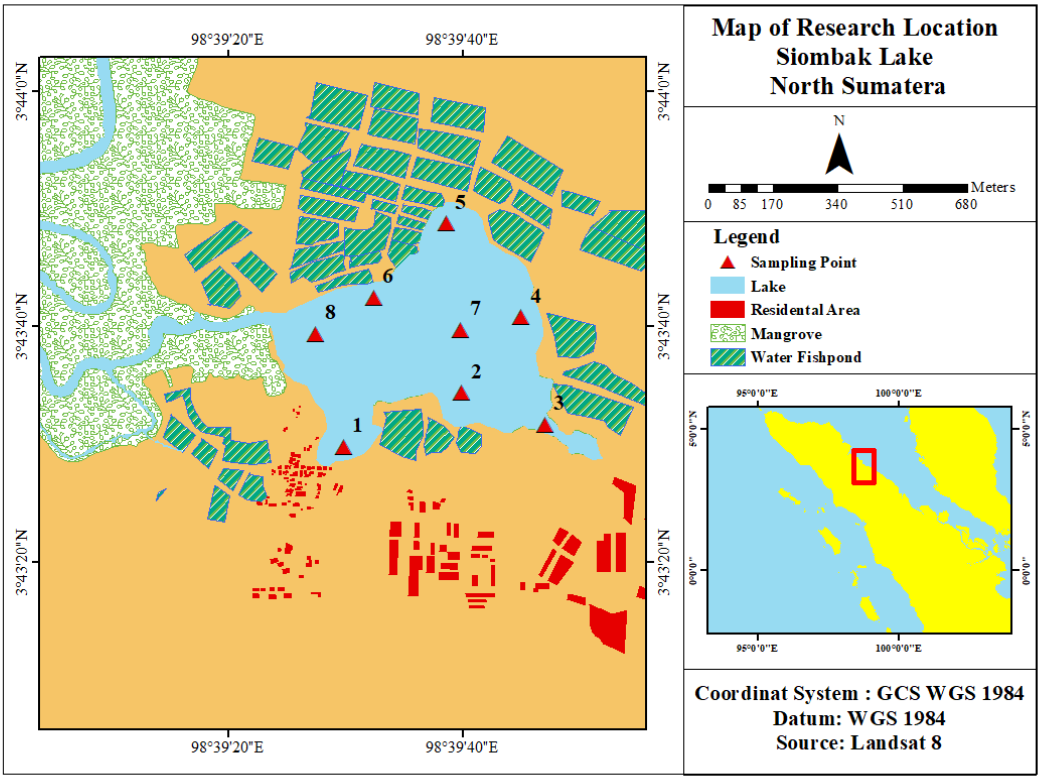

Figure 1. Location of the tropical coastal lake, Medan-Indonesia.

Siombak Lake's measured mean sea level (MSL) is 1.12 m during the rainy and 1.10 m during the dry season. When it rains, the average lake depth is between 2.96 and 5.26 m; when it is dry, it is between 2.96 and 4.90 m (Muhtadi et al 2020a).

Ponds (in the north), tourism (in the east), settlements (in the south), and some mangrove forests (in the west, north, and southeast) are among the land use types found in the area surrounding this lake (Muhtadi et al 2020b). There were eight data collection points located within the lake (Figure 1). Data was collected every month, from September 2018 to August 2019.

Procedures of water sample collection and measurement. Water was measured and sampled for an entire month between September 2018 and August 2019. During the high tide (evening) and low tide (morning), measurements were performed and water samples were collected (in the morning). The water samples were a mixture of surface, middle, and bottom water samples taken using a 5 L Kemmerer water sampler. Rice et al (2017) study's method was used to conduct water quality testing and measurement. Water quality parameters such as temperature, salinity, pH, dissolved oxygen, and water transparency were determined in the field; the other parameters were further analyzed in the laboratory. Water samples were then mixed and divided into two containers: 1) 500 mL (without preservatives) for TSS, TDS, turbidity, and conductivity 2) 1,000 mL for BOD, COD, NO_3, and PO_4 (stored at 4ºC). A flow-watch meter is used to measure the current.

Siombak Water Quality Index (SWQI) is a composite of quality parameters of lake and estuary waters that are affected by tides. As a result, the selection of critical parameters are tailored to the peculiarities of Lake Siombak's waters, a type of tropical tidal lake. SWQI development, which included the following steps:

1) Selection of parameters

The parameter selection process is critical for estimating the extent of water pollution (Mitra et al 2018; Sim & Tai 2018; Sutadian et al 2018). The selection of parameters has a more significant impact on the WQI value than the number of parameters employed (Li et al 2019; Nguen & Sevando 2019; Ma et al 2020). The essential criteria used to determine water quality can be chosen based on expert assessment (Sutadian et al 2017; Kachroud et al 2019) or quantitative analysis using PCA (Li et al 2019; Nguen & Sevando 2019; Ma et al 2020).

PCA was used to select water quality factors in this study. This method is on Ma et al (2020) study's demonstration of PCA appropriateness due to the precision of quality attributes assessment. All 14 variables (Table 1 and Table 2) were examined using Spearman's rank correlation coefficient (rs), a nonparametric approach that considers the variables' interactions. Variables with no significant association (Table 3) are omitted from the analytic method (Ma et al 2020). Microsoft Office Excel 2016 and SPSS 21.0 were used to do all mathematical and statistical calculations.

The Spearman rank correlation coefficient (rs) analysis of 14 variables reveals a significant association during high tide, except for pH. At low tide, however, temperature, pH, and water clarity, do not substantially correlate with the other factors. Correlations between variables are included in the subsequent analysis, together with the variable normalization.

The findings of the PCA analysis indicate that the number of variables with high loadings (>0.70) decreased from 14 to 9 (Table 4). However, it fluctuates between high tide and low tide: salinity, TSS, phosphate, and water discharge are removed at high tide, while at low tide the parameters water transparency, TSS, and EC are excluded from the model.

Table 1

The result of water quality measurement during the high tides at Lake Siombak

Month	Salinity ($^{0}/_{00}$)	Temp. (^{0}C)	pH	DO (mg L^{-1})	TDS (mg L^{-1})	TSS (mg L^{-1})	EC (mS/cm)	Turbidity (NTU)	BOD (mg L^{-1})	COD (mg L^{-1})	Nitrate (mg L^{-1})	Phosphate (mg L^{-1})	Water discharge (m^3 s^{-1})	Water transparency (m)
Sep	6±2.09	30.2±0.49	7.5± 0.18	4.7±1.2	8,888.75 ±2,922	13.70±2.00	9.16 ±2.46	17.45±2.23	10.55±1.31	32.96±4.09	7.49± 1.65	3.30± 2.95	22.08±4.78	0.71±0.11
Oct	5±2.10	30.2±0.51	7.1± 0.15	4.7±1.1	9.125,00 ±2,153	11.18±2.75	9.11 ±2.19	6.99±1.46	11.36±1.45	35.50±4.54	3.93± 1.58	2.14± 1.90	16.84±5.28	0.81 ±0.12
Nov	6±1.52	29.4±0.20	7.2± 0.06	2.8±0.5	11.575,83 ±3,482	21.21±26.70	10.50 ±3.23	4.50±3.21	9.76±4.47	30.49±13.96	4.87± 0.60	2.96± 3.87	35.95±13.23	0.79 ±0.17
Dec	6±1.43	30.0±0.38	7.7± 0.30	4.3±0.8	12.280,00 ±4,354	9.64±6.56	11,59 ±3.72	5.46±8.42	12.14±2.39	37.95±7.47	5.24± 2.46	2.03± 3.12	67.53±10.26	0.77 ±0.18
Jan	8±2.76	30.0±0.40	7.4± 0.15	4.4±0.5	14.378,75 ±832	23.55±14.45	8.70 ±2.67	6.91±1.77	11.64±3.62	36.38±11.33	4.84± 2.47	3.37± 2.28	64.82±9.83	0.75 ±0.10
Feb	8±2.16	30.6±0.24	7.4± 0.21	3.6±0.6	9.036,67 ±3,136	73.80±79.77	8.25 ±2.53	36.73±48.25	215.43± 210.59	1.221,79 ±1,053.06	3.23± 2.26	2.33± 1.59	43.01±7.71	0.56 ±0.11
Marc	13±2.16	31.3±0.69	7.4± 0.18	3.6±1.1	25.481,25 ±1,319	49.91±68.30	20.29 ±0.98	6.50±8.12	146.00± 85.62	513.13±271.48	1.68± 1.64	1.36± 0.51	34.44±11.85	0.86 ±0.11
Apr	13±1.42	30.9±0.57	7.4± 0.21	3.5±0.9	21.106,25 ±2.271	29.55±38.89	16.45 ±1.46	4.81±3.78	100.25± 118.89	326.31 ±389.31	2.57± 2.56	1.94± 0.71	43.47±11.19	0.87 ±0.19
May	7±2.99	30.5±0.42	7.3± 0.12	3.9±1.3	6.290,63 ±2,330	72.91±55.65	6.49 ±2.39	25.27±41.72	38.52±41.33	286.47±301.38	4.60± 2.44	3.28± 1.94	26.47±7.00	0.69 ±0.09
June	8±2.18	28.2±0.34	7.5± 0.19	3.2±1.1	6.790,63 ±1,894	104.45± 138.91	7.33 ±1.88	36.22±51.59	66.22±36.53	239.11±117.93	3.39± 2.43	0.79± 0.71	31.28±9.30	0.64 ±0.09
July	7±1.63	30.8±0.48	7.3± 0.22	2.5±1.2	3.382,50 ±593	102.55± 156.88	3.24 ±1.20	61.81± 109.24	18.39±6.12	195.38±93.15	9.36± 2.52	2.45± 1.97	15.19±2.74	0.52 ±0.06
Aug	10±2.30	30.2±0.46	7.2± 0.14	2.3±0.3	4.883,13 ±446	60.86±43.01	10.05 ±1.14	6.76±4.93	17.25±5.00	612.00±312.45	3.30± 1.77	2.58±1 .82	17.15±3.68	0.77 ±0.21
Min	5	29.4	7.1	2.3	3.382,50	9.64	3.24	4.50	9.76	30.49	1.68	0.79	15.19	0.35
Max	13	31.3	7.7	4.7	25.481,25	104.45	20.29	61.81	215.43	1.221,79	9.36	3.37	67.53	1.20
Aver.	8.39	30.38	7.35	3.51	11.302,78	50.87	10.18	18.36	58.81	321.32	4.28	2.38	34.85	0.73
St dev	2.81	0.53	0.17	0.79	6.833,23	34.66	4.70	19.16	68.36	358.30	2.00	0.80	17.53	0.16

Table 2

The result of water quality measurement during low tides at Lake Siombak

Month	*Salinity* (ppt)	*Temp.* *(^{0}C)*	*pH*	*DO* *(mg L^{-1})*	*TDS* *(mg L^{-1})*	*TSS* *(mg L^{-1})*	*EC* *(mS cm^{-1})*	*Turbidity* *(NTU)*	*BOD* *(mg L^{-1})*	*COD* *(mg L^{-1})*	*Nitrate* *(mg L^{-1})*	*Phosphate* *(mg L^{-1})*	*Water discharge* *(m^3 s^{-1})*	*Water transparency (m)*
Sep	8±1.40	30.9± 0.67	7.4± 0.29	3.7±2.93	9,941.25± 3.73	12.67± 1.63	8.30±1.71	14.60±3.49	13.21±1.71	41.29±5.35	7.67± 1.65	2.35± 2.95	22.08±4.78	0.71±0.11
Oct	8±1.78	31.7± 0.88	7.0± 0.16	3.7±1.67	8,938.75± 1.79	11.38± 4.21	8.70±1.54	6.51±1.41	12.05±3.37	37.65±10.53	4.99± 1.58	2.47± 1.90	16.84±5.28	0.81 ±0.12
Nov	6±1.87	28.6± 0.41	72± 0.12	24±1.29	11,481.25± 3.74	18,25± 17.60	10.11±3.49	4.31±3.71	16.73±2.53	52.28±7.92	4.73± 0.60	2.52± 3.87	35.95±13.23	0.79 ±0.17
Dec	6±1.56	29.1± 0.38	7.2± 0.10	2.,5±0.93	11,771.25± 2.59	8.63± 5.60	11.41±4.39	3.85±4.76	10.64±2.44	33.25±7.63	6.01± 2.46	3.29± 3.12	67.53±10.26	0.77 ±0.18
Jan	11±2.64	30.7± 0.56	7.6± 0.30	2.3±0.91	15,136.25± 1.79	48.00± 16.89	9.11±0.93	6.50±2.06	14.52±2.67	45.38±8.33	5.78± 2.47	3.15± 2.28	64.82±9.83	0.75 ±0.10
Feb	9±2.69	29.7± 0.65	7.3± 0.13	3.4±1.01	8,921.88± 3.72	68.31± 52.13	8.39±3.71	8.93±12.83	138.71± 172.21	436.74± 550.91	3.72± 2.26	2.08± 1.59	43.01±7.71	0.56 ±0.11
Marc	13±2.24	30.3± 0.48	7.1± 0.06	21±0.58	24,331.25± 2.38	71.63± 69.20	17.76±3.63	5.36±3.35	388.94±2 39.43	1,272.13± 811.94	3.37± 1.64	1.70± 0.51	34.44±11.85	0.86 ±0.11
Apr	12±1.64	30.7± 0.44	7.2± 0.10	1.4±0.28	20,431.25± 4.88	47.38± 20.46	15.11±1.61	3.43±0.48	180.69±57.99	633.63±207.13	3.97± 2.56	1.86± 0.71	43.47±11.19	0.87 ±0.19
May	10±3.46	30,0± 0.72	7.2± 0.15	2.1±0.54	6,472.06± 2.42	93.69± 90.98	6.70±2.49	11.61±14.34	35.38±38.37	133.04±144.08	5.21± 2.44	3.24± 1.94	26.47±7.00	0.69 ±0.09
June	7±2.08	31.0± 0.69	7.4± 0.10	3.0±0.72	7,595.63± 2.86	104.81± 83.02	6.88±1.86	31.88±44.98	84.78±32.19	315.81±107.54	3.32± 2.43	1.53± 0.71	31.28±9.30	0.64 ±0.09
July	8±2.50	30.3± 0.48	70± 0.13	1.7±0.55	3.553,75± 6.09	52.88± 38.88	3.35±1.24	366.50±342.80	18.50±4.44	428.75±505.08	9.25± 2.52	2.80± 1.97	15.19±2.74	0.52 ±0.06
Aug	12±2.64	30.5± 0.49	7.0± 0.09	1.4±0.76	5,096.25± 5.83	74.06± 57.12	10.09±1.13	9.98±9.69	19.42±2.28	545.00±391.42	3.60± 1.77	2.94± 1.82	17.15±3.68	0.77 ±0.21
Min	6	28.6	7.0	1.4	3,553.75	8.63	3.35	3.43	10.64	33.25	3.32	1.53	15.19	0.35
Max	13	31.7	7.6	3.7	24,331.25	104.81	17.76	366.50	388.94	1,272.13	9.25	3.29	67.53	1.20
Aver.	9.26	30.24	719	2.36	11,248.14	54.45	9.78	41.71	83.67	357.60	4.90	2.51	34.85	0.73
t dev	2.42	0.87	0.18	0.76	6,441.18	32.11	3.97	108.01	116.65	375.43	1.73	0.64	17.53	0.16

Table 3

Correlation among the variables using Spearman's rank correlation coefficient as a nonparametric test

	Variable	*Spearman's rank correlation*														
		Sal	*Temp*	*pH*	*DO*	*TDS*	*TSS*	*EC*	*Turb*	*WT*	*BOD*	*COD*	*NO_3*	*PO_4*	*Water discharge*	
High tide	Sal	1.000	.224	-.221	-.581*	.238	.385	.329	-.182	.047	.601*	.678*	-.350	-.168	.421	Low tide
	Temp	.539	1.000	.095	.238	.007	.042	-.182	.301	.079	-.070	-.084	-.126	-.406	-.011	
	pH	.151	-.014	1.000	.361	.298	.025	-.102	0.000	-.549	-.011	-.221	.049	-.126	-.148	
	DO	-.427	-.091	.260	1.000	.046	-.403	-.273	.140	.040	-.466	*-.669**	.154	-.172	-.156	
	TDS	.186	.028	.263	.350	1.000	-.434	.797**	-.811**	.151	.070	-.007	-.105	-.224	.081	
	TSS	.557	.371	-.091	-.608*	-.524	1.000	-.329	.497	-.449	.713**	.643*	-.580*	-.252	.175	
	EC	.221	.042	.147	.014	.741**	-.587*	1.000	-.895**	.471	.140	.217	-.350	-.112	.182	
	Turb	.105	.259	.046	-.105	-.755**	.720**	-.853**	1.000	-.255	0.000	.007	.140	-.063	.007	
	WT	.260	.035	-.195	-.098	.607*	-.474	.863**	-.856**	1.000	-.352	-.104	-.032	.054	.202	
	BOD	.785**	.692*	.165	-.287	.070	.671*	-.056	.336	-.095	1.000	.923**	-.692*	-.615*	.646*	
	COD	.827**	.580*	-.011	-.399	-.084	.615*	.014	.315	.042	.888**	1.000	-.615*	-.510	.723**	
	NO_3	-.781**	-.406	.158	.210	-.357	-.266	-.406	.196	-.526	-.657*	-.727**	1.000	.622*	-.382	
	PO_4	-.438	-.462	.112	.364	-.126	-.413	-.154	-.014	-.182	-.608*	-.455	.643*	1.000	-.667*	
	Water discharge	.182	-.259	.530	.189	.720**	-.287	.441	-.490	.221	.161	.056	-.154	.147	1.000	

** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed); WT - water transparency.

Table 4

Loading of selected variables on significant PCs for the Siombak Lake

Variable	*High tide*				*Low tide*			
	VF1	*VF2*	*VF3*	*VF4*	*VF1*	*VF2*	*VF3*	*VF4*
Salinity	.529	.411	.575	-.250	.390	.347	.713*	-.203
Temperature	-.023	.234	.929*	-.071	-	-	-	-
DO	.034	-.197	.077	.875*	-.040	.128	-.922*	.120
TDS	.736*	.172	.481	.337	.564	.589	.304	.348
TSS	-.568	.363	.242	-.617	.147	-.001	.238	-.934*
EC	.855*	.175	.422	.132	.521	.697	.370	.281
Turbidity	-.912*	.100	.240	-.268	.095	-.951*	.141	-.016
WT	.965*	-.215	.024	-.017	-	-	-	-
BOD	.024	.869*	.437	.053	.846*	.343	.249	-.139
COD	-.119	.886*	.155	-.192	.812*	.094	.461	-.259
NO_3	-.702*	-.573	-.093	.099	-.236	-.781*	-.037	.493
PO_4	-.171	-.319	-.501	.470	-.808*	-.206	.354	.270
Water discharge	.301	.325	-.241	.646	.811*	-.100	.139	.047
Total	4.927	3.914	1.371	1.004	5.133	1.946	1.368	1.349
% of Variance	37.897	30.108	10.549	7.724	46.663	17.689	12.435	12.268
Cumulative %	37.897	68.005	78.553	86.277	46.663	64.352	76.787	89.055

(-) Not analyzed because the correlation value is not significant. *strong loadings (>0.70).

2) Weight determination (wi)

Weight determination (wi) is required to ascertain the significance (impact) of factors in determining water quality in a variety of methods (Kangabam et al 2017; Stadian et al 2018; Nguyen & sevando et al 2019). Lobato et al (2015), supported by Yuvaraj et al (2018) and Li et al (2019), stated that PCA analysis is the most appropriate method for determining the weight (wi), as it is directly related to the features of these waters. In this SWQI approach, the wi values result from the PCA normalization. To aid in their understanding, the Varimax rotation was conducted using the Factor Analysis (FA). Following that, new variables, dubbing the variable factors (VFs), were created (Mitra et al 2018; Ma et al 2020). In this method, for the determination of each wi, in the PCA analysis, the proportion of the loading variable factor (VF) in multi-varimax PCA analysis (Rotated component matrix) was used (Table 5). The quantity wi is the weight corresponding to the i-th parameter (a number between 0 and 1), which is assigned according to its importance to the overall water quality status. The total weight (wi) is equal to 1. The weight (wi) is determined according to the equation (Ma et al 2020):

$$wi = \frac{|VF_{ij}| \ x \ A_j}{\sum_{i=1}^{n} |VF_{ij}| \ x \ A_j}; \ \sum_{i=1}^{n} wi = 1 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ 1)$$

Where:
wi - ith weight parameter;
VFij - the highest value of the jth variable loading factor of the i-th parameter;
Aj - initial Eigenvalue of the jth variable loading factor;
i - ith parameter;
n - number of selected parameters.

Table 5

Weights assigned to the selected parameters using the PCA

Variable	*High tide*			*Low tide*		
	Variable factor (|VFj|)	*Weight factor (|VFj|*Aj)*	*Final weight (w_i)*	*Variable factor (|VFj|)*	*Weight factor (|VFj|*Aj)*	*Final weight (w_i)*
Sal	-	-	-	.713	.975	.043
Temp	.929	4.578	.120	-	-	-
DO	.875	4.312	.113	.922	1.262	.056
TDS	.736	3.626	.095	-	-	-

	High tide			*Low tide*		
Variable	*Variable factor (|VFj|)*	*Weight factor (|VFj|*Aj)*	*Final weight (w_i)*	*Variable factor (|VFj|)*	*Weight factor (|VFj|*Aj)*	*Final weight (w_i)*
TSS	-	-	-	.934	1.260	.055
EC	.855	4.214	.111	-	-	-
Turb	.912	4.493	.118	.951	1.850	.081
WT	.965	4.752	.125	-	-	-
BOD	.869	4.282	.112	.846	4.343	.191
COD	.886	4.364	.115	.812	4.169	.184
NO_3	.702	3.457	.091	.781	1.520	.067
PO_4	-	-	-	.808	4.149	.183
Water discharge	-	-	-	.811	4.162	.183
Total	7.729	38.077	1.000	7.579	22.716	1.000

(-) Not included because the VF did not reach 0.70.

3) The determination of sub-index value (Si)

Sutadian et al (2018) used equations 2 and 3 to determine the sub-index value (Table 6). The determination of Si for TSS, turbidity, BOD, COD, nitrate, and phosphate parameters refers to equation 2. Salinity parameters, if the measured concentration is 5-25 (ppt) use equation 2, if the salinity concentration is <5 ppt or >25 ppt use equation 3. EC parameter, if the measured concentration is 5-25 (mS cm^{-1}) using equation 2, if the salinity concentration is <5 mS cm^{-1} or >25 mS cm^{-1} using equation 3. TDS parameter 5,000-25,000 (mg L^{-1}) using equation 2, if the TDS concentration is <5,000 mg L^{-1} or >25,000 mg L^{-1} using equation 3. The pH parameter, if the measurement results are >7 use equation 2, but if the measurement results are <7 use equation 3. Temperature Parameters, if the measurement results are 27-30°C use equation 2, if the temperature concentration is <27°C or >30°C use equation 3. Equation 4 is used for the water discharge. The Si determination refers to the following equations (Sutadian et al 2018):

$$S_i = S_1 - \left[(S_1 - S_2)\left(\frac{c_i - X_1}{X_2 - X_1}\right)\right] \qquad \text{......................................2)}$$

$$S_i = S_1 - \left[(S_1 - S_2)\left(\frac{X_1 - c_i}{X_2 - X_1}\right)\right] \qquad \text{......................................3)}$$

Where:
Si - the sub-index value;
X_i - the measurement data;
S_1 and S_2 - the sub-index values corresponding to the upper and lower threshold of the class, respectively;
X_1 and X_2 - values of the permissible upper and lower thresholds of the class.

4) Final value of index

The final SWQI value is defined by equation 4, established by Gupta et al (2003), based on the mathematical model of WQI calculation (the weighted arithmetic mean function),adjusted for estuarine and coastal waters. Sim & Tai (2018), Sutadian et al (2018) and Li et al (2019) also employed this equation (Nguyen & Sevando 2019). SWQI is calculated as follows:

$$SWQI = \prod_{i=1}^{n} S_i^{w_i} \qquad \text{......................................4)}$$

Where:
SWQI - the index value;
n - the number of sub-indices;
w_i - ith weight;
S_i - the ith sub-index.

The weights (w_i) indicate the relative importance of the water quality parameter i in SWQI. The pollution level classification through the SWQI, referring to Sutadian et al

(2018), is done according to the following categories: 100 ≥ SWQI ≥ 90 (Excellent); 90 > SWQI ≥ 75 (Good), 75 > SWQI ≥ 50 (Fair), 50 > SWQI ≥ 25 (Marginal), and 25 > SWQI ≥ 5 (Poor).

Table 6

Water quality parameter and sub-index value

No	*Parameter's class*	*Parameters' thresholds*	*Sub index (between 100 and 5)*	*No*	*Parameter's class*	*Parameters'[1] thresholds*	*Sub index[1] (between 100 and 5)*
1	Temperature (^{0}C) [1]			6	Salinity ($^0/_{00}$)*		
	Class 1	30	Si = 100		Class 1	5-25	Si=100-75
	Class 2	27-33	Si=100-75		Class 2	<5 or >25	Si=75-50
	Class 3	25-27 or 33-40	Si=75-50	7	EC (mS cm^{-1}) *		
					Class 1	5-25	Si=100-75
	Class 4	< 25 or > 40	Si=5		Class 2	<5 or >25	Si=75-50
2	TSS (mg L^{-1}) [1]			8	TDS (mg L^{-1}) [1]		
	Class 1	0-20	Si=100		Class 1	5,000-25,000	Si=100-75
	Class 2	20-30	Si=100-75		Class 2	<5,000 or >25,000	Si=75-50
	Class 3	30-50	Si=75-50				
	Class 4	50-400	Si=50-5	9	Turbidity (NTU)		
	Class 5	>400	Si=5		Class 1	< 5	Si=100
3	DO (mg L^{-1}) [1]				Class 2	5-20	Si=100-75
	Class 1	≥6	Si=100		Class 3	20-30	Si=75-50
	Class 2	4-6	Si=100-75		Class 4	30-100	Si=50-5
	Class 3	3-4	Si=75-50		Class 5	>100	Si=0
	Class 4	2.04-3	Si=50-5	10	Nitrate (mg L^{-1}) [2,4]		
	Class 5	< 2	Si=5		Class 1	0-0.5	Si=100
4	BOD (mg L^{-1}) [2,4]				Class 2	0.5-1	Si=100-75
	Class 1	0-6	Si=100		Class 3	1-5	Si=75-50
	Class 2	6-20	Si=100-75		Class 4	5-10	Si=50-5
	Class 3	20-30	Si=75-50		Class 5	>10	Si=5
	Class 4	30-50	Si=50-5	11	Phosphate (mg L^{-1}) [1]		
	Class 5	< 50	Si=5		Class 1	0-0.2	Si=100
5	COD (mg L^{-1}) [1]				Class 2	0.2-0.4	Si=100-75
	Class 1	6-10	Si=100		Class 3	0.4-1	Si=75-50
	Class 2	4-6	Si=100-75		Class 4	1-5	Si=50-5
	Class 3	3-4	Si=75-50		Class 5	>5	Si=5
	Class 4	2.04-3	Si=50-5	12	Water discharge (m^3 s^{-1}) ……… ………………. (4)		
	Class 5	< 2	Si=5		Si=1.2553x+12.886 (R^2 = 0.9859)		
				13	Water transparency	Percentage depth secchi	

Source: modified from: [1]Sutadian et al (2018); [2]Pesce & Wunderlin (2000); [3]Li et al (2019) and [4]Nguyen & Sevando (2019); * brackish category 5-25 ppt (Odum & Barret 2005).

Results. Temperature and pH levels are constant in Lake Siombak waters throughout both high and low tides. Temperatures range between 28.6 and 31.7°C (±1), whereas pH values range between 7.0 and 7.7 (±0.2) (Table 1 and Table 2). In general, the tropical region's temperature is constant with few variations. In brackish water, the pH value is very stable between 7 and 8.5, with relatively minimal fluctuations (Odum & Barret 2005). This situation indicates that coastal lake waters are waters that have high alkalinity. Sim & Tai (2018) stated that temperature and pH are the two stable water quality parameters in tropical waterways. This result is consistent with those obtained by Sajinkumar et al (2017) and Barik et al (2017) in tropical Coastal Lake in India (Akulum and Chilika Lake), as well as by Ratnayake et al (2018) in Coastal Bolgoda Lake (Sri Lanka), indicating that the pH and temperature values remain stable throughout the year. It is, however, different from what Raposo et al (2018) observed in a tropical coastal lagoon (Brazil), with a more variable pH and temperature. The pH and temperature values are more variable than in the subtropics (Elshemy et al 2016; Jamila et al 2016; Bhattrai et al 2017).

The other water quality measures are highly unpredictable throughout the dry season (Feb-Jul), being significantly greater during the rainy season (Aug-Jan), except for NO_3 and PO_4, which are lower during the dry season. COD values range from 35.79 to 1,021.14 mg L^{-1}, while BOD values range from 4.75 to 305.91 mg L^{-1}. Both metrics have a tenfold increase in value during the wet season. In general, Lake Siombak's organic matter and nutrient concentrations are high compared to other coastal lakes (Jamila et al 2016; Barik et al 2017; Raposo et al 2018; Ratnayake et al 2018) or to Indian and Chinese estuaries (Ramasamy et al 2015; Yuvaraj et al 2018; Li et al 2019).

In general, the high value of BOD and COD is due to the Belawan riverinputs of domestic and industrial waste from the Belawan and Medan Marelan areas, including the landfills of Medan City at the Belawan River's headwaters. The lower BOD and COD readings during the dry season result from the Belawan river's considerable discharge during the wet season, which dilutes the dissolved elements. As a result, the concentration of dissolved elements is lower during the dry season than during the wet season. This result showed evidence that the salinity and EC values were higher than during the rainy season.

Lake Siombak's quality status is poor, with an average SWQI of 25 at high tide and only 19 at low tide (Figure 2). The "superior" condition of Station 8 was owing to the fact that it accumulates less organic debris. Station 8 is an inlet where organic debris are frequently "swept" away by the flow of water pushed into the lake, mainly at station 7. On the lake itself, stations 2 and 7 are more polluted than other places, due to a deeper waters, promoting accumulation at the lake bottom. As previously stated, the primary pollutants in Lake Siombak are organic matter (BOD & COD) and phosphate. These pollutants are confined at stations 1, 2, and 7, located at greater depths than other places (Muhtadi et al 2020a). Although the residence duration of the water is short (8-10 hours), water change happens only at the surface (1-3) due to the lake's halocline at a depth of 4 meters. As a result, organic and dissolved matter are trapped at the bottom of the waters, particularly at stations 1, 2, and 7. The tide dynamics prevent an algal bloom in Lake Siombak, as a result of "water washing" on the surface. Thus, at high tide, the water conditions are apparently better than at low tide, because the entering water is "fresher" and more dilute, resulting in less dissolved and organic materials.

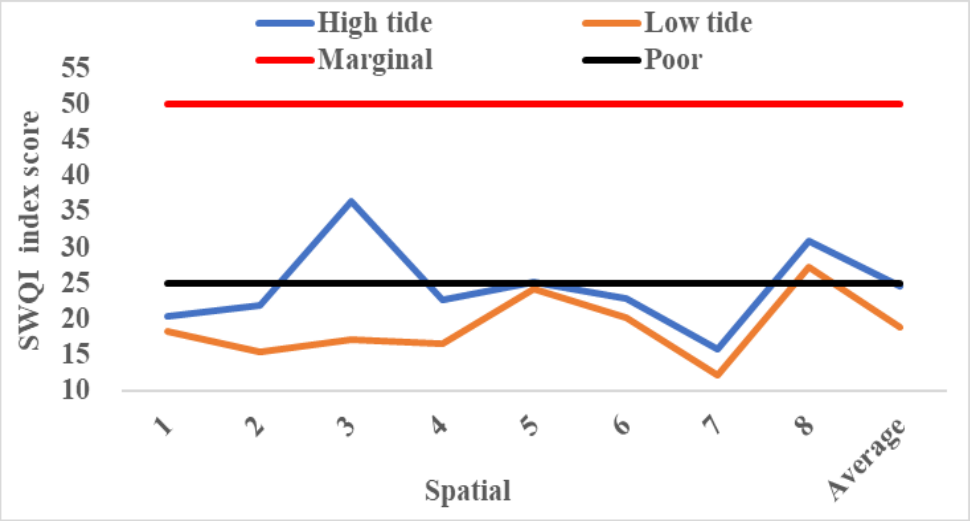

Figure 2. Spatially, water quality status calculated by SWQI in Lake Siombak.

Lake Siombak is generally worse during the dry season than during the wet season. This scenario occurs as a result of excessive rainfall entering the waters, diluting the concentration of contaminants. Thus, during the dry season, pollutants become more concentrated, resulting in an increase in the concentration of pollutants (mainly organic, COD, and BOD) in the waterways. Additionally, as illustrated in Figure 3, the water conditions for the Siombak Lake are slightly worse at low tide than at high tide. At low tide, contaminants at the bottom and in the sediments are brought to the surface, creating the illusion that the chemicals are more significant at high tide. According to Sheela et al (2012) the concentration of dissolved compounds is greater near the bottom than at the surface.

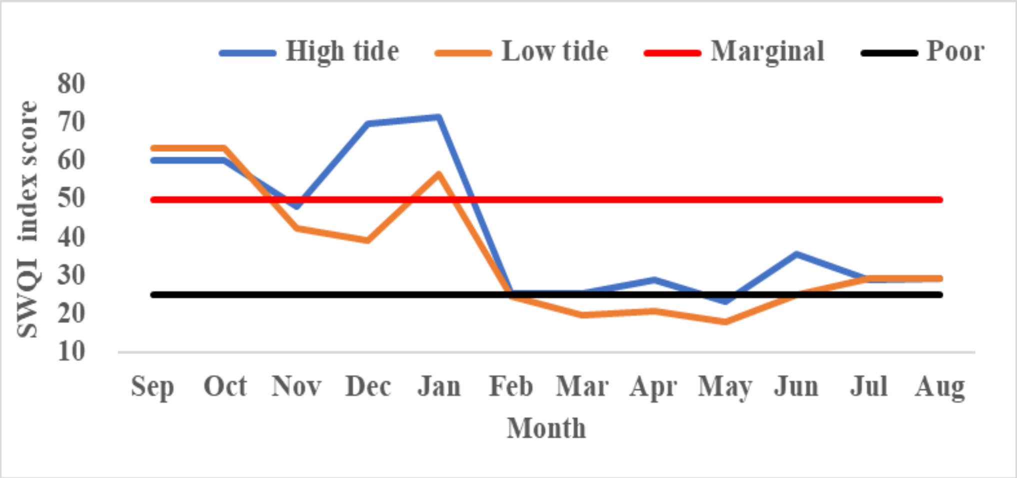

Figure 3. Temporally, water quality status calculated by SWQI in Lake Siombak.

According to pollution studies conducted on coastal lakes, Lake Siombak is one of the most contaminated. Additional research findings on the coastal lakes include moderate to good water quality in Akkulam-Veli Lake (Sheela et al 2012) and Nokoue Lake (Zandagba et al 2017). Even the Greek coastal lagoon is better(Christia et al 2014). Lake Siombak is more polluted than other estuaries, including the Parangipettai estuary on India's Southeast Coast (Yuvaraj et al 2018), the estuary area of Lake Wuli in China (Wang et al 2019), the Eastern Pearl River Delta estuary in China (Li et al 2019), and the southern coast of Vietnam (Nguyen & Sevando 2019).

Discussion. PCA is a type of multivariate data analysis that can reduce the number of variables in a dataset to a manageable level, while maintaining the data's authenticity (Sutadian et al 2016; Tripathi & Singal 2019; Ma et al 2020). The normalization of data variables in this study was accomplished by using PCA, which included 14 variables in a standard data set used to calculate the weights (wi). To characterize the water quality characteristics of Lake Siombak, an FA analysis using Varimax rotation of PCs was used to extract the eigenvalues (eigenvalues greater than 1) and the major factors significantly contributing to the characterization of the water quality in Lake Siombak. The analysis revealed that the VFs were different at low and high tides (Table 4).

At high tide, the 4 VF (eigen values) are greater than one, which explains 86.28% of the Lake Siombak waters quality change. VF1 accounted for 37.90% of the overall variation, even though only 5 variables had significant loading values (>0.70), namely TDS, EC, turbidity, water transparency, and nitrate. TSS and turbidity are physical factors that correlate negatively with water transparency, with a greater TSS or turbidity indicating a lower brightness value. VF2 explained 30% of the overall variance, with just two factors having a high loading (>0.75), namely BOD and COD. In Lake Siombak, VF2 is defined by organic matter (BOD & COD). VF3, accounting for 10.55% of the water quality status change, is defined by the temperature variable, while, VF4, accounting for 7.72% of the water quality status change, is defined by the dissolved oxygen content. At high tide in Lake Siombak, the primary pollutants are suspended matter, organic matter, and nitrate.

At low tide, there were 4 VFs, which account for 89.06 % of the condition of Lake Siombak's waters. VF1 accounted for 46.66 % variance, with four vitally influencing variables (VF values greater than 0.75): BOD, COD, phosphate, and water discharge. At low tide, VF1 is characterized by dissolved and organic matter. This was in stark contrast to the tide condition, in which the suspended material becomes variable and affects VF1. The discrepancy may be caused by the water inflow during the high tide, which carries more suspended matter, clouding the waters and reducing their brightness. At low tide, the volume of water decreases, causing the dissolved materials to become more "dense" and organic matter at the bottom of the waters to be "lifted" to the surface. VF2 is defined by turbidity and nitrate, which vary by a total of 17.69%. The VF3 is defined by the dissolved oxygen content, which varies by a total of 12.43%. At low tide, DO affects VF3 due to the low and fluctuating DO value. The low DO value is caused by a high concentration of organic matter and a decrease in brightness near the water's bottom. Muhtadi et al (2020a) explained that when the water in Lake Siombak recedes, the water level can drop by 1-2 m, implying that the water volume can be reduced by at least 30-40%. VF4 with a total variance of 12.29%, is defined by TSS. According to the tidal circumstances, the primary pollutants in Lake Siombak at low tide include organic matter, suspended matter, and nutrients. At low tide, organic matter (BOD & COD), nutrients, and turbidity are more prevalent than at high tide. According to Pérez-Ruzafa et al (2019) and Raposo et al (2018), the primary contaminants in coastal lake waters are organic matter and nutrients.

Weight determination by expert opinion often results in the greatest DO weight (Ott 1978; Sim & Tai 2018; Sutadian et al 2018). According to Akkoyunlu & Akiner (2012) and Quevedo-Castro et al (2018), some experts assign the most prominent weight to nitrate or phosphate, while others to otganic matter (BOD or COD) (Nguyen & Sevando 2019). While PCA is used to determine the effect of factors on individual sites, the SWQI index demonstrates a difference in weight (wi) between high tides and low tides. Water transparency, temperature, and turbidity have the highest wi values at high tide, while BOD, COD, phosphate, and water discharge have the highest wi values at low tide. Although dissolved oxygen is little in weight, it is taken into account during high and low tides. Organic matter (BOD and COD) is a variable with a considerable weight in the Lake Siombak, both at low and high tides, therefore it will have a significant impact on establishing the lake's pollution status.

Various sub-index values (Si) also contribute to the final index value. This difference makes sense given the differences in water quality, particularly the physical separation between the tropics and subtropics. For example, discharge is very influential in estuary waters. Water discharge is one of the key parameters of water quality, which can affect the distribution of turbidity, salinity and water temperature in estuaries (Alizadeh et al 2018; Li et al 2019). For example, Li et al (2019) assigned a value of 100 if the river discharge reaches 1000 $m^3\ s^{-1}$, because the river water discharge in the Eastern Pearl River Delta, China can reach 1,000 $m^3\ s^{-1}$. however, the maximum water discharge measured in the Belawan River is only 67 $m^3\ s^{-1}$. Thus, the figure of 70 $m^3\ s^{-1}$ for the discharge sub-index at Lake Siombak is a realistic value, because the maximum measured discharge is 67 $m^3\ s^{-1}$. Thus, geographical differences affect the parameters and sub-index values used to calculate the water quality index.

Conclusions. There was a significant variation between high and low tides in this area study. At high tide, pH has no significant correlation with other factors, but, at low tide, several variables, including pH, temperature, and water clarity, have no significant correlation with other variables. After normalizing the data with varimax rotation, it is evident that salinity, TSS, phosphate, and surface current can be in the model for high tide. TDS and EC are omitted at low tide. As a result of the PCA analysis, it is possible to conclude that the principal pollutants in Lake Siombak are organic matter (BOD and COD), suspended matter, and nutrients. SWQI values in the created model can be used to assess the water quality of Lake Siombak. The lake water quality in the sea, as determined by SWQI, is deplorable, particularly during the dry season from February to August. As a result, the study urges more surveillance, particularly during the dry season.

Acknowledgements. The authors would like to thank to Lake Siombak Team – Students of Aquatic Resource Management, Universitas Sumatera Utara, for the field's help.

Conflict of interest. The authors declare no conflict of interest.

References

Alizadeh M. J., Kavianpour M. R., Chau K. W., 2018 Effect of river flow on the quality of estuarine and coastal waters using machine learning models. Engineering Applications of Computational Fluid Mechanics 12(1):810-823

Akkoyunlu A., Akiner M. E., 2012 Pollution evaluation in streams using water quality indices: A case study from Turkey's Sapanca Lake Basin. Ecological Indicators 18:501–511.

Barik S. K., Muduli P. R., Mohanty B., Behera A. T., Mallick S., Das A., Samal R. N., Rastogi G., Pattnaik A. K., 2017 Spatio-temporal variability and the impact of Phailin on water quality of Chilika lagoon. Continental Shelf Research 136:39–56.

Bassi N., Kumar M. D., 2017 Water quality index as a tool for wetland restoration. Water Policy 19(3):390–403.

Bhattrai B. D., Kwak S., Choi K., Heo, W., 2017 Long-term Changes of Physicochemical Water Quality in Lake Youngrang, Korea. Korean Journal of Ecology and Environment 50(1):169–185.

Christia C., Giordani G., Papastergiadou E., 2014 Assessment of ecological quality of coastal lagoons with a combination of phytobenthic and water quality indices. Marine Pollution Bulletin 86(1–2):411–423.

Elshemy M., Khadr M., Atta Y., Ahmed A., 2016 Hydrodynamic and water quality modeling of Lake Manzala (Egypt) under data scarcity. Environmental Earth Sciences 75 (19):1–13.

Gupta A. K., Gupta S. K., Patil R. S., 2003 A comparison of water quality indices for coastal water. Journal of Environmental Science and Health - Part A 38(11):2711–2725.

Indirawati S., 2017 Pollution of Pb and Cd and health complaints to communities in the Belawan Coastal Area. Jurnal Jumantik 2(2):54–60.

Jamila H., Mouldi B., Moncef G., 2016 Assessment of the water quality of Bizerte Lagoon of Tunisia by use of statistical analyses. Journal of Waste Water Treatment & Analysis 7(2):1–9.

Kachroud M., Trolard F., Kefi M., Jebari S., Bourrié, G., 2019 Water quality indices: Challenges and application limits in the literature. Water 11(2):1–26.

Kangabam R. D., Bhoominathan S. D., Kanagaraj S., Govindaraju M., 2017 Development of a water quality index (WQI) for the Loktak Lake in India. Applied Water Science 7(6):2907–2918.

Li S., Chen X., Singh V.P., He Y., Bai X., 2019 An improved index for water quality evaluation in an estuary region: A case study in the Eastern Pearl River Delta, China. Water Policy 21(2):310–325.

Lobato T. C., Hauser-Davis R. A., Oliveira, T. F., Silveira A. M., Silva H. A. N., Tavares M. R. M., Saraiva A. C. F., 2015 Construction of a novel water quality index and quality indicator for reservoir water quality evaluation: A case study in the Amazon region. Journal of Hydrology 522:674–683.

Ma Z., Li H., Ye Z., Wen J., Hu Y., Liu Y., 2020 Application of modified water quality index (WQI) in the assessment of coastal water quality in main aquaculture areas of Dalian, China. Marine Pollution Bulletin 157:1–8.

Mitra S., Ghosh S., Satpathy K. K., Bhattacharya B. D., Sarkar S. K., Mishra P., Raja, P., 2018 Water quality assessment of the ecologically stressed Hooghly River Estuary, India: A multivariate approach. Marine Pollution Bulletin 126:592–599.

Muhtadi A., Yulianda F., Boer M., Krisanti M., Rahmadya A., Sontos, 2020a Hydrodynamics of tropical tidal lake waters Lake Siombak, Medan, Indonesia. AACL Bioflux 13(4):2014–2031.

Muhtadi A., Yulianda F., Boer M., Krisanti M., 2020b Spatial distribution of mangroves in tidal lake ecosystem. Proc. Indonesian International Conference on Agriculture, Environment and Food Security (AEFS). IOP Conference Series: Earth and Environmental Science 454:012131.

Muhtadi A., Yunasfi Y., Leidonald R., Sandy S. D., Junaidy A., Daulay A. T., 2016 Limnological status of Lake Siombak, Medan, North Sumatra. Oseanologi dan Limnologi di Indonesia 1(1):39–55.

Nguyen N. T. T., Sevando M., 2019 Assessing coastal water quality through an overall index. Polish Journal of Environmental Studies 28(4):2321–2330.

Odum E. P., Barrett G. W., 2005 Fundamental of ecology. Brooks/Cole Publishing Co, Salt Lake City, 574 p.

Ott W. R., 1978 Environmental indices: theory and practice. Ann Arbor Science Publishers, Michigan, 371 p.

Panda A., Pattnayak N., 2013 Coastal Water Pollution Index (CWPI) – a tool for assessing coastal water quality along the North East Coast of India. International Journal of Scientific & Engineering Research 4(6):1-6.

Pérez-Ruzafa A., Campillo S., Fernández-Palacios J. M., García-Lacunza A., García-Oliva M., Ibañez H., Navarro-Martínez P. C., Pérez-Marcos M., Pérez-Ruzafa I. M., Quispe-Becerra J. I., Sala-Mirete A., Sánchez O., Marcos C., 2019 Long-term dynamic in nutrients, chlorophyll a, and water quality parameters in a coastal lagoon during a process of eutrophication for decades, a sudden break and a relatively rapid recovery. Frontiers in Marine Science 6:1-23.

Pesce S. F., Wunderlin D. A., 2000 Use of water quality indices to verify the Córdoba City (Argentina) on Suquía River. Water Resources 34(11):2915–2926.

Quevedo-Castro A., Rangel-Peraza J. G., Bandala E., Amabilis-Sosa L., Rodríguez-Mata A., Bustos-Terrones Y., 2018 Developing a water quality index in a tropical reservoir using multiparameter meter. Journal of Water, Sanitation and Hygiene for Development 8(4):752–766.

Ramasamy S. M., Muthukumar M., Subagunasekar M., 2015 Water quality index of estuarine environment. Current Science 108(8):1430–1433.

Raposo D., Clemente I., Figueiredo M., Vilar A., Lorini M. L., Frontalini F., Martins V., Belart P., Fontana L., Habib R., Laut L., 2018 Benthic foraminiferal and organic matter compounds as proxies of environmental quality in a tropical coastal lagoon: The Itaipu lagoon (Brazil). Marine Pollution Bulletin 129(1):114–125.

Ratnayake A. S., Ratnayake N. P., Sampei Y., Vijitha A V. P., Jayamali S. D., 2018 Seasonal and tidal influence for water quality changes in coastal Bolgoda Lake system, Sri Lanka. Journal of Coastal Conservation 22(6):1191–1199.

Rice E. W., Baird R. B., Eaton A. D., 2017 Standard methods for the examination of water and wastewater. American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF), 1500 p.

Sajinkumar K. S., Revathy A., Rani V. R., 2017 Hydrogeochemistry and spatio-temporal changes of a tropical coastal wetland system: Veli-Akkulam Lake, Thiruvananthapuram, India. Applied Water Science 7(3):1521–1534.

Sheela A. M., Letha J., Joseph S., Chacko M., Sanal K. S. P., Thomas J., 2012 Water quality assessment of a tropical coastal lake system using multivariate cluster, principal component and factor analysis. Lakes and Reservoirs 17(2):143–159.

Sim S. F., Tai S. E., 2018 Assessment of a physicochemical indexing method for evaluation of tropical river water quality. Journal of Chemistry ID 8385369:1–12.

Sutadian A. D., Muttil N., Yilmaz A. G., Perera B. J. C., 2016 Development of river water quality indices—a review. Environmental Monitoring and Assessment 188(1):1–29.

Sutadian A. D., Muttil N., Yilmaz A. G., Perera B. J. C., 2017 Using the analytic hierarchy process to identify parameter weights for developing a water quality index. Ecological Indicators 75:220–233.

Sutadian A. D., Muttil N., Yilmaz A. G., Perera B. J. C., 2018 Development of a water quality index for rivers in West Java Province, Indonesia. Ecological Indicators 85:966–982.

Tripathi M., Singal S. K., 2019 Use of principal component analysis for parameter selection for development of a novel water quality index: A case study of river Ganga India. Ecological Indicators 96:430–436.

Wang J., Fu Z., Qiao H., Liu F., 2019 Assessment of eutrophication and water quality in the estuarine area of Lake Wuli, Lake Taihu, China. Science of the Total Environment 650:1392–1402.

Wepener V., Cyrus D. P., Vermeulen L. A., O'brien G. C., Wade P., 2006 Development of a water quality index for estuarine water quality management in South Africa. WRC Report, Water Research Commission, Pretoria, South Africa, 118 p.

Wu Z., Zhang D., Cai Y., Wang X., Zhang L., Chen Y., 2017 Water quality assessment based on the water quality index method in Lake Poyang: The largest freshwater lake in China. Scientific Reports 7(1):1–10.

Yuvaraj P., Satheeswaran T., Damotharan P., Karthikeyan V., Jha D. K., Dharani G., Balasubramanian T., Kirubagaran R., 2018 Evaluation of the environmental quality of Parangipettai, Southeast Coast of India, by using multivariate and geospatial tool. Marine Pollution Bulletin 131(Part A):239–247.

Zandagba E. J. B., Adandedji F. M., Lokonon B. E., Chabi A., Dan O., Mama D., 2017 Application Use of Water Quality Index (WQI) and multivariate analysis for Nokoué Lake water quality assessment. American Journal of Environmental Science and Engineering 1(4):117–127.

*** CCME, Canadian Council of Ministers of the Environment, 2017 Canadian Water Quality Guidelines for the Protection of Aquatic Life: CCME Water Quality Index User’s Manual 2017 Update.

*** DoE, Department of Environment, 2012 Malaysia environmental quality report 2012. Department of Environment Ministry of Environment and Water, Malaysia.

*** DoE, Department of Environment, 2017 Malaysia marine water quality standard and index. Department of Environment Ministry of Environment and Water, Malaysia.

*** MoE, Ministry of Environment, 2003 [Guidelines for determining water quality status, Number 15]. Ministry of Environment of the Republic of Indonesia. [In Indonesian].

Received: 30 November 2022. Accepted: 17 January 2023. Published online: 28 January 2023.

Authors:
Ahmad Muhtadi, Universitas Sumatera Utara, Faculty of Agriculture, Aquatic Resources Management, Jl. Prof A. Sofyan No. 3, 20155, Medan, North Sumatra, Indonesia, e-mail: ahmad.muhtadi@usu.ac.id
Fredinan Yulianda, IPB University, Faculty of Fisheries and Marine Sciences, Aquatic Resources Management, Jl. Lingkar Akademik, Kampus IPB, 16680, Bogor, West Java, Indonesia, e-mail: fredinan@apps.ipb.ac.id
Mennofatria Boer, IPB University, Faculty of Fisheries and Marine Sciences, Aquatic Resources Management, Jl. Lingkar Akademik, Kampus IPB, 16680, Bogor, West Java, Indonesia, e-mail: mboer@ymail.com
Majariana Krisanti, IPB University, Faculty of Fisheries and Marine Sciences, Aquatic Resources Management, Jl. Lingkar Akademik, Kampus IPB, 16680, Bogor, West Java, Indonesia, e-mail: krisanti.m@gmail.com
Etty Riani, IPB University, Faculty of Fisheries and Marine Sciences, Aquatic Resources Management, Jl. Lingkar Akademik, Kampus IPB, 16680, Bogor, West Java, Indonesia, e-mail: etty_riani_harsono@yahoo.com
Rusdi Leidonald, Sumatera Utara University, Faculty of Agriculture, Aquatic Resources Management, Jl. Prof A. Sofyan No. 3, 20155, Medan, North Sumatra, Indonesia, e-mail: rusdi.leidonald@usu.ac.id
Qadar Hasani, Lampung University, Faculty of Agriculture, Department of Aquatic Resources, Jl. Prof. Sumantri Brojonegoro No. 1, Gedong Meneng, 35145, Bandar Lampung, Lampung, Indonesia, e-mail: masqod@fp.unila.ac.id
Muhammad Reza Cordova, National Research and Innovation Agency (BRIN), Earth Sciences Research Organizations, Research Center for Oceanography, Jalan Pasir Putih 1, Ancol Timur, Pademangan, 14430, Jakarta Utara, Jakarta, Indonesia, e-mail: muhammad.reza.cordova@lipi.go.id

How to cite this article:
Muhtadi A., Yulianda F., Boer M., Krisanti M., Riani E., Leidonald R., Hasani Q., Cordova M. R., 2023 Assessment of pollution status of tropical coastal lakes using modified Water Quality Index (WQI) based on physio-chemical parameters. AACL Bioflux 16(1):356-370.