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Water Quality Dynamics and Water Pollutions of Belawan Estuary, North Sumatra, Indonesia

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Abstract
The Belawan Estuary is a highly strategic area in Medan, North Sumatra Province. Various utilisation activities such as ports, transportation, industry, fisheries, tourism, and settlements in the Belawan Estuary area have resulted in ecological pressures, particularly water pollution. The aim of this study was to determine the water quality dynamics and pollution status of the Belawan Estuary. The study was conducted in October 2023 in the Belawan Estuary, Medan City, North Sumatra Province. The sampling points consisted of eight locations representing the mouth, middle, and outer parts of the estuary. Sampling was conducted four times following the tidal cycle: full moon, last quarter, new moon, and first quarter. Water pollution status was determined using the pollution index (PI), Malaysian Marine Water Quality Index (MMWQI), and Canadian Council of Ministers of the Environment (CCME) methods. Temperature and pH were the most stable quality parameters. Total dissolved solids (TDS) and salinity fluctuated both spatially and temporally. Spatially and temporally, the Belawan Estuary falls into the moderately to heavily polluted category. The sources of pollution in the Belawan Estuary are urban activities, primarily the Terjun landfill. Nutrients and coliform bacteria are the main water quality parameters contributing to Belawan estuary pollution.

Keywords: Aquatic pollution, Belawan, Estuary, Tide, Water quality.

1. Introduction

An estuary is an area where freshwater and seawater meet, resulting in brackish water (Nybakken & Bertness 2005; Odum & Barrett 2005). Estuarine ecosystems are complex and highly dynamic owing to tidal fluctuations and river flow (Guo 2022; Kowalewska-Kalkowska and Marks 2016). Generally, estuaries consist of river mouths, deltas, and coastal lagoons (Leidonald *et al.*, 2023; Muhtadi *et al.*, 2020; Nybakken &Bertness 2005; Odum & Barrett 2005; Rangkuti *et al.*, 2017). Estuaries receive inputs of minerals and organic matter from both rivers and oceans, making them highly eutrophic ecosystems. Estuarine ecosystems are crucial in coastal regions because they represent an ecotone between freshwater and marine ecosystems (Hopkinson *et al.*, 2019; Wolanski & Elliott 2016). Organisms in estuaries are diverse and complex as they provide habitats for various freshwater, brackish, and marine organisms (Pelage *et al.*, 2021). Estuaries have long been recognised as the spawning, nursery, and feeding grounds for various aquatic organisms, making them essential for coastal fishing activities. Estuaries, along with other coastal ecosystems, such as mangroves, seagrasses, and coral reefs, play a crucial role in supporting coastal fishery production (Berkström *et al.*, 2020; Pelage *et al.*, 2021).

Strategic estuarine areas between freshwater and marine ecosystems serve as a "connector" for land and sea activities. Therefore, estuarine areas are often developed into ports and trade, urban, and industrial zones (Rangkuti *et al.*, 2017; van Neer *et al.*, 2023). Additionally, estuarine areas inevitably become fishing grounds because of the crucial habitats provided by estuarine ecosystems (Berkström *et al.*, 2020). Consequently, various activities in estuaries exert ecological pressure, including habitat degradation and water pollution (Freeman *et al.*, 2019; Hitchcock & Mitrovic 2019; Tseng *et al.*, 2021; Woodland *et al.*, 2022).

Studies on various estuaries in Indonesia and other major cities worldwide have indicated high ecological pressures, particularly pollution. The conditions in the Jakarta Bay Estuary range from mild to severe pollution (DLH, 2023). The Tangerang Bay Estuary also exhibits moderate to severe pollution (Gumelar *et al.*, 2017; Prismayanti *et al.*, 2021). The water conditions in Semarang Estuary indicate heavy pollution (Haeruddin *et al.*, 2019). The Cirebon City Estuary in West Java experiences mild-to-moderate pollution (Hidayah *et al.*, 2021). The Belawan River Estuary is a promising estuary with a strategic location, making it an international port in Western Indonesia. Located north of Medan City, North Sumatra Province, the Belawan Estuary is a center for industrial growth in Medan. Various activities in the surrounding area, including upstream activities in the Karo and Deli Serdang regions, undoubtedly affect the water conditions and quality of the Belawan Estuary. Therefore, this study aimed to understand the dynamics of water quality in relation to tidal cycles and assess the pollution levels in the Belawan Estuary.

2. Methods

2.1 Sampling site

This study was conducted in October 2023 in the Belawan Estuary of North Sumatra Province. Sampling was conducted for approximately one month at eight stations (Figure 1) following the tidal cycle. Sampling was performed using purposive sampling. The selection of locations represents the upper, middle, and mouth of the river and estuary canal. Physical, chemical, and biological parameters were measured both in and ex situ. Sample analysis was performed at the Laboratory of Environmental Health and Disease Control Technology Center (BTKLPP) Class 1 Medan and the Laboratory of Research, Water Resource Management Study Program, Faculty of Agriculture, Universitas Sumatera Utara.

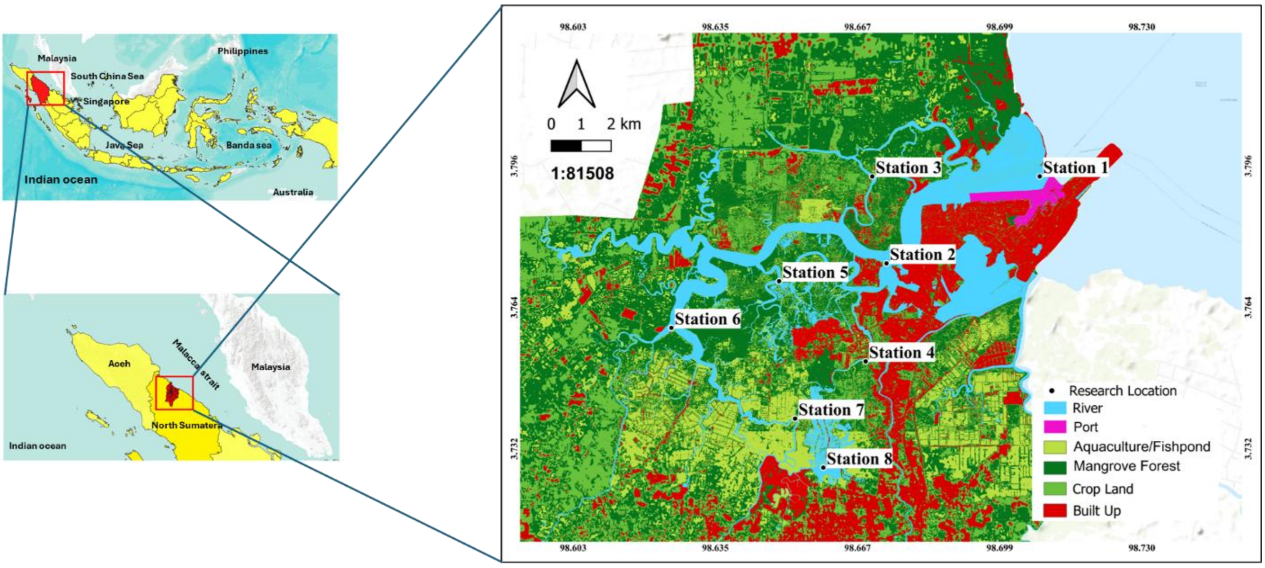

Figure 1. Location map sampling

2.2. Measurement and sampling.

The measurement and sampling of water follow the APHA standard (APHA, 2017), which includes the physical, chemical, and biological parameters of water (Table 1). Water quality parameters are measured at high and low tide, as well as 4 measurements that follow the tidal cycle, namely the new moon, first quarter, full moon, and last quarter.

2.3. Data analysis.

The methods to determine the pollution level in the Belawan estuary used were the Pollution Index, the Canadian Council Minister of the Environment (CCME), and the Malaysia Marine Water Quality Index (MMWQI). The pollution index (PI) was calculated by considering the concentration value of a parameter with its maximum standard (Ci/Lij) and the average value of several water quality parameters from a single or one-time water quality data collection activity.

Table 1. Measurement of physical, chemical, and biological parameters

Parameter	Unit	Tools/method	locations
Temperature	°C	DO meter Lutron P51	*In situ*
TDS/Total Dissolved Solid	mg/L	HACH, HQ40D	*Ex situ*
TSS/ Total Suspended Solids	mg/L	HACH, HQ40D	*Ex situ*
Turbidity	NTUs	Turbidity meter	*In situ*
Salinity	PPT	Refractometer	*In situ*
DO/ Dissolved Oxygen	mg/L	DO meter	*In situ*
COD/ Chemical Oxygen Demand	mg/L	Spectrophotometer/reflux method	*Ex situ*
BOD/ Biochemical Oxygen Demand	mg/L	Iodometry/DO Incubations	*Ex situ*
NO_3/Nitrate	mg/L	Spectrophotometer/Brucine acid	*Ex situ*
PO_4/Phosphate	mg/L	Spectrophotometer/ The molybdenum-blue method	*Ex situ*
Oil & grease	mg/L	Oil Content Analyser	*Ex situ*
Faecal coliform	number/100ml	most probable number (MPN)	*Ex situ*

The steps for the pollution index calculation (Nemerow, 1991; MoE, 2003) were as follows:

1. Calculate the value of Ci/Li for each parameter at each sampling location using the following formula:

$$\left(\frac{Ci}{Li}\right) \text{measurement results} = \frac{Ci}{Li}$$

Ci = measurement results; Li = water quality standards

2. Determine the standard parameters that do not have a range, but if they do have a range (for temperature and pH), calculate the Ci ≤ Li, average as follows:

$$\left(\frac{\mathrm{C}i}{\mathrm{L}i}\right) \text{calculation} = \frac{[\mathrm{C}im - (\mathrm{L}i)\text{average}]}{[(\mathrm{L}i)\text{minimum} - (\mathrm{L}i)\text{average}]}$$

For Ci ≥ Li, calculate the average as follows:

$$\left(\frac{\mathrm{C}i}{\mathrm{L}i}\right) \text{calculation} = \frac{[\mathrm{C}im - (\mathrm{L}i)\text{average}]}{[(\mathrm{L}i)\text{maximum} - (\mathrm{L}i)\text{average}]}$$

where Cim = maximum concentration of quality standards

3. If the decreasing concentration value of a parameter, such as dissolved oxygen (DO) with a saturation, the Ci/Li value of the measurement is replaced by the Ci/Li value calculated using the following formula:

$$\left(\frac{Ci}{Li}\right) new = \frac{Cim - Ci\ (measurement\ result)}{Cim - Li}$$

c_{im} = super saturation of oxygen at a certain temperature

4. If the calculated Ci/Li value is > 1, then:

$$\left(\frac{\mathrm{C}i}{\mathrm{L}i}\right) \text{calculation} = \mathrm{P.}\log\left(\frac{\mathrm{C}i}{\mathrm{L}i}\right) \text{measurement results}$$

where P is a constant whose value is arbitrarily determined and adjusted based on environmental observations and the desired requirements for a specific purpose (typically, a value of 5 is used).

5. Determine the average value and maximum value overall, then calculate the pollution index (PI) using the following formula:

$$IP = \sqrt[2]{\frac{\left(\frac{Ci}{Li}\right)^2 \text{maximum} + \left(\frac{Ci}{Li}\right)^2 \text{average}}{2}}$$

Information: PI = pollution index, which is a function of Ci/Li Li Li = maximum permissible limit (standard), Ci = measured concentration of water quality parameter (i) Water quality classification based on the PI Method: 0–1 (good); 2–5 (slightly polluted); 6–10 (moderately polluted), and > 10 (heavily polluted) (MoE, 2003)..

The Canadian Council of Ministers of the Environment (CCME) was used to obtain water quality data by comparing the data with standard guidelines. CCME has been used in Canada and other countries to determine sediment, drinking water, and agricultural quality. The CCME was calculated using the following formula (CCME 2017):

F1 (Scope) indicates the percentage of variables that do not meet the standard guidelines for at least one measurement period (failed variables) relative to the total number of measured variables.

$$\text{F1} = \frac{\text{Number of failed parameters}}{\text{Total number of parameters}} x100$$

F2 (Frequency) indicates the percentage of tests for each parameter that did not meet standard guidelines (failed tests).

$$\text{F2} = \frac{\text{Number of failed tests}}{\text{Total number of tests}} x100$$

F3 (Amplitude) represents the extent to which the failed test values did not meet the standard guidelines. F3 is calculated in three steps. When each concentration is greater or less than the standard, it is called a deviation:

$$\text{excursion}_i = \frac{\text{FailedTestValue}_i}{\text{Objective}_j} - 1$$

If the parameter value is less than or equal to the standard,

$$\text{excursion}_i = \frac{\text{Objective}_j}{\text{FailedTestValue}_i} - 1$$

The normalised deviation sum (NSE), ranging from 0 to 100, was calculated by dividing the deviation from the standard by the total number of tests:

$$nse = \frac{\Sigma\ \text{excursion}_i}{\#\ \text{of test}} - 1$$

After obtaining the NSE value, the F3 value was calculated using the formula:

$$\text{F3} = \frac{nse}{0{,}01\ nse + 0{,}01} \times 100$$

If the factor values are obtained, the CCME value can be calculated using the following formula:

$$\text{CCME} = 100 - \left[\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732}\right]$$

Information:

F1 = Number of parameters not meeting water quality standards

F2 = Number of test results not meeting water quality standards

F3 = Magnitude of difference between the test results for a parameter and its standard; 1.732 = normalised value 0–100

Water Quality Classification based on the CCME Method is as follows 95–100 (excellent); 80–94 (good); 65–79 (fair); 45–64 (marginal); 0–44 (poor) (CCME, 2017).

Seawater quality data were collected for analysis according to the Malaysian Environmental Quality Report 2016 and reported based on the Marine Water Quality Index (MWQI). The MWQI is used to reflect the status of seawater quality and consists of seven main parameters (dissolved oxygen (DO), nitrate (NO_3), phosphate (PO_4), ammonia (NH_3), *Fecal* coliform, oil and Grease

(O&G), and total suspended solids (TSS). Water Quality Categories were determined according to the MMWQI, as follows: 90–100 (excellent), 80–89 (good), 50–79 (moderate), and 0–49 (poor) (DoE 2017). The formula for MMWQI (DoE, 2017) is as follows:

$$\text{MMWQI}= q\ Do^{0.18}\ x\ qfC^{0.19}\ x\ q\ NH3^{0.15} x\ qNO3^{0.16}\ x\ q\ PO4^{0.17}\ x\ q\ TSS^{0.15}$$

Qi DO : -85.816+55.4768 (DO) – 4.142 (DO^2)
If DO < 3 qi DO = 10
If DO > 10 qi DO = 10
Qi FC : 100*EXP$^{[-0.005\ (\textit{Fecal coliform})]}$
If FC> 500 qi FC = 8
Qi NO_3: 94.8EXP $^{[0.00035\ (\text{nitrat})]}$
Qi PO_4: 95.2EXP $^{[-0.002\ (\text{phosphate})]}$
If PO> 0.9 mg/L, qi PO_4 = 10
qi TSS: 95.8 EXP $^{[-0.0043\ (\text{TSS})]}$
If TSS > 100 mg/L, qi TSS = 20

3. Result and Discussion

3.1. Water quality dynamics

Spatially and temporally, the temperature and pH in the Belawan Estuary are stable. The temperature ranged between 29 and 32 °C, and the pH ranged between 7.0 and 7.9. Temperature changes in tropical regions are not significant because sunlight is available throughout the year (Nybakken & Bertness, 2005; Odum & Barrett, 2005). The pH concentration in the brackish water was relatively stable between 7 and 8.5, with relatively small fluctuations (Odum & Barrett 2005). This indicated that the estuarine waters were buffered. Research conducted in Lake Siombak (part of the Belawan Estuary) for one year also showed stable temperatures and pH concentrations (Muhtadi *et al.*, 2023). Similarly, tropical coastal lakes exhibit stable temperatures and pH concentrations (Barik *et al.*, 2017; Ratnayake *et al.*, 2018; Sajinkumar *et al.*, 2017). However, compared with subtropical estuaries, there are significant differences in temperature and pH concentrations, which are more variable (Jamila *et al.*, 2016; Raposo *et al.*, 2018).

Salinity and Total Dissolved Solids (TDS) concentrations fluctuated spatially and temporally. Spatially, salinity and TDS concentrations were higher near the estuary/sea and lower near the river. This is because of the influence of seawater, which has a higher salt content and mixes with freshwater, resulting in lower concentrations near the river where the tidal range decreases. Temporally, salinity and TDS concentrations were higher during the full moon and new moon periods than during the first and second quarter moons. This is due to higher tidal forces during the full moon and new moon periods compared to that in the first and last quarter (Leidonald et a., 2024; Muhtadi & Leidonald, 2024; Muhtadi *et al*., 2024). This can also be observed in the water level during the full moon and new moon periods, which was higher than that during the first and last quarters.

Tidal currents in the Belawan estuary also showed spatial and temporal variations. Spatially, the currents at St6–St8 (near the coast) were higher than those near the estuary/sea. This was mainly due to the narrower channel/river section at St6–St8, resulting in higher currents. Temporally, the tidal currents during the full-moon and new-moon periods were higher than those during the first and last quarters. During the full moon tide, the positions of the Moon and Sun are aligned with the Earth, resulting in the maximum gravitational force from the moon and sun (Putro & Lee 2020; Leidonald et a., 2024; Muhtadi *et al*., 2024). This causes the sea level to rise to its highest level, resulting in faster currents (EI *et al*., 2023; Rose *et al*., 2022).

The Belawan Estuary, which serves as the mouth of the Belawan River, is a deposition site for sediments and organic matter. The measurements showed low clarity (< 0.5 m) and high turbidity (> 10 NTU). Sediment particles transported from the river and deposited at the river mouth reduce the penetration of sunlight. Turbidity is caused by suspended and dissolved organic and inorganic materials, such as suspended solids from drainage channels that discharge into the sea. Temporally, the highest turbidity occurred during the full moon phase because of the high-water level, resulting in significant mixing during high tide and sediment settling during low tide. Tides play a crucial role in forming seawater circulation patterns and distribution patterns of suspended materials (Leidonald et a., 2024; Muhtadi & Leidonald, 2024; Muhtadi *et al*., 2024).

Nutrient measurements, such as nitrate and phosphate, indicated that their concentrations were much higher than the threshold set by the government regulations of the Republic of Indonesia, namely, more than 0.06 mg/L (nitrate) and 0.015 mg/L (phosphate). Besides being a sediment deposition site, the estuarine area is also an ecosystem where nutrients accumulate from both the land/river and the sea, including the surrounding mangrove ecosystem. The decomposition or weathering of mangrove plants is a natural source of nutrients in the estuarine ecosystem (Pérez-Ruzafa *et al*., 2019). Spatially, the nitrate and phosphate levels were higher in the river area (St6–St8) compared than in the estuary area (St1–St5). This is suspected to be because there is a landfill in Medan near St7, which leads to higher nutrient levels (Muhtadi *et al*., 2023, 2020).

Based on research conducted in the Belawan Estuary, spatial Biochemical Oxygen Demand (BOD) test results ranged from 5.7 mg/L to 10.5 mg/L during high tide and 3.3 mg/L to 15.2 mg/L during low tide. Temporally, it ranged from 3.3 mg/L to 15.2 mg/L during high tide and 3.3 mg/L to 14.3 mg/L during low tide. Meanwhile, spatial Chemical Oxygen Demand (COD) ranged from 18.7 mg/L to 25.0 mg/L, and temporally BOD concentrations ranged from 5.7 mg/L to 10.7 mg/L. The higher concentration of COD compared to that of BOD was due to the oxidation of inorganic compounds. All organic matter (95–100%) can be oxidized by strong oxidants such as potassium permanganate in an acidic environment. The higher the COD value, the more oxygen is required to oxidize the organic pollutants (APHA, 2017).

Spatially, this shows that organic matter (BOD and COD) was more prevalent in the estuarine area (St1–5) compared than in the river section (St6–8). This indicated the accumulation of organic matter at the river mouth. Temporally, organic matter was higher during the last quarter phase than during other phases because it is suspected that more pollutants enter from the land owing to lower high tides, causing the organic materials not to be diluted (Sajinkumar *et al*., 2017).

Based on research conducted in the Belawan Estuary, the oil and grease test results ranged from 1.4 mg/L to 2.6 mg/L, exceeding the quality standards, which would undoubtedly endanger the environment. Oil and grease in water float on the surface because they have a lower density than water. Accumulated layers of oil and grease block sunlight from entering the water, preventing aquatic plants from photosynthesizing (Ratnayake *et al*., 2018). Based on research conducted in the Belawan Estuary, *Fecal coliform* test results ranged from 1287.5 CFU/100 mL to 6830 CFU/100 mL, which can pose risks to domestic use. *Fecal coliform* bacteria found in water indicate the presence of other pathogens. *Fecal* coliform bacteria are an indicator of human or animal *Fecal* contamination in water. Spatially, *Fecal coliform* levels were lower in estuarine areas (with high salinity) because coliform bacteria cannot survive for long periods in high salinity conditions. Coliform bacteria in high-salinity water can survive for only a few hours (Abmi *et al*., 2021; Glory and Takarina, 2020).

Tabel 2. Spatial characteristics of water quality during high tide in the Belawan Estuary, Medan, Indonesia

Parameters	Units	Water Quality Standards *	Observation Locations							
			St1	St2	St3	St4	St5	St6	St7	St8
Temperature	°C	± 3	30.0	30.3	30.0	30.8	29.5	29.2	31.0	31.7
Salinity	psu	0–34	17.0	11.8	14.0	15.3	10.8	0.0	3.3	1.0
Turbidity	NTU	5	20.5	19.8	19.4	22.4	19.2	42.7	21.4	11.2
Water transparency	m	-	0.5	0.4	0.4	0.6	0.4	0.3	0.3	0.5
Depth	m	-	2.3	2	1.6	2	2.2	2.1	2.2	2.1
TSS	mg/L	80	23.4	26.3	21.4	27.6	27.0	20.5	21.8	17.4
TDS	mg/L	-	10,746.0	7,815.0	7,992.5	13,677.5	10,792.5	3,831.6	5,574.5	6,113.0
Oil and Grease	mg/L	1	2.2	1.8	2.0	1.9	2.0	1.8	2.5	2.3
Current	cm/s	-	8.9	6.2	13.8	12.5	11.0	14.1	15.1	7.1
DO	mg/L	>5	6.5	7.5	6.6	4.6	5.3	6.3	5.5	5.9
pH	-	78.5	7.6	7.4	7.5	7.0	7.6	7.9	7.5	7.9
BOD	mg/L	20	7.6	7.1	7.4	7.1	7.4	6.1	6.9	5.6
COD	mg/L	-	25.0	23.4	24.3	23.2	24.3	19.9	22.8	18.7
Nitrate	mg/L	0.06	3.7	3.6	4.4	4.2	6.1	7.2	4.6	4.3
Phosphate	mg/L	0.015	1.0	0.7	0.3	0.6	0.5	0.5	1.6	1.7
Fecal coliform	MPN /100 ml	-	967.5	1.460.0	832.5	2,175.0	6,742.5	10,335.0	9,392.5	8,665.0

* PP (2021) in Appendix VIII; MPN: Most Probably Number

Table 3. Spatial characteristics of water quality during low tide in the Belawan Estuary, Medan, Indonesia

Parameter	Units	Water Quality tandards *	Observation Locations							
			St1	St2	St3	St4	St5	St6	St7	St8
Temperature	°C	± 3	30.1	30.2	29.6	30.6	29.7	29.4	30.6	32.0
Salinity	psu	0–34	14.8	11.8	9.3	15.3	10.3	1.8	2.0	1.5
Turbidity	NTU	5	20.8	19.2	19.4	22.2	30.4	32.2	18.2	12.8
Water transparency	m	-	0.6	0.4	0.4	0.6	0.4	0.3	0.3	0.4
Depth	m	-	1.1	0.9	0.6	1.1	1	1.4	0.9	0.9
TSS	mg/L	80	17.8	19.9	19.7	18.9	25.5	21.6	30.4	27.0
TDS	mg/L	-	9,992.8	8,630.0	6,949.0	12,147.5	8,620.0	6,060.7	5,870.0	1,907.5
Oil and Grease	mg/L	1	1.4	1.4	1.9	1.7	1.8	1.7	2.6	2.5
Current	cm/s	-	5.9	9.3	5.8	6.8	10.3	10.5	13.2	15.8
DO	mg/L	>5	6.2	7.4	6.7	4.3	6.1	5.5	5.4	5.8
pH	-	7–78.5	7.6	7.6	7.5	7.1	7.2	7.4	7.4	7.8
BOD	mg/L	20	7.1	6.7	7.3	7.2	7.2	5.7	10.6	5.7
COD	mg/L	-	23.6	22.1	24.0	23.6	23.6	18.7	19.0	18.2
Nitrate	mg/L	0.06	4.4	4.3	5.5	6.0	8.3	7.2	6.1	5.1
Phosphate	mg/L	0.015	0.2	0.2	0.7	0.7	0.4	0.4	2.1	1.9
Fecal coliform	jml/100ml	-	220.0	4,835.0	4,317.5	5,817.5	6,385.0	5,080.0	6,600.0	5,385.0

* PP (2021) in Appendix VIII

Table 4. Temporal characteristics of water quality in the Belawan Estuary, Medan, Indonesia

Parameters	Units	Water Quality Standards *	Waktu Pengamatan							
			Full Moon		Last Quarter		New Moon		First Quarter	
			HT	LT	HT	LT	HT	LT	HT	LT
Temperature	°C	± 3	31.3	31.4	30.2	30.3	30.3	30.2	29.5	29.3
Salinity	psu	0–34	12.0	12.4	4.4	3.9	11.3	10.0	8.9	7.0
Turbidity	NTU	5	26.4	27.6	19.4	19.7	21.5	21.9	21.0	18.3
Water transparency	m	-	0.3	0.4	0.6	0.5	0.3	0.3	0.4	0.4
Depth	m	-	2.4	0.3	1.6	0.7	2.3	0.2	1.6	0.9
TSS	mg/L	80	16.6	16.6	14.0	15.5	13.3	13.8	48.8	44.5
TDS	mg/L	-	10,198.0	8,967.1	4,824.0	4,883.0	10,298.2	9,051.9	7,951.1	7,186.8
Oil and Grease	mg/L	1	2.6	2.3	2.1	2.0	0.7	0.8	2.8	2.3
Current	cm/s	-	11.7	8.6	6.7	7.8	13.3	11.6	10.7	8.7
DO	mg/L	>5	5.9	5.9	5.2	4.9	6.6	6.6	6.4	6.3
pH	-	7–78.5	7.8	7.7	7.4	7.4	7.4	7.3	7.6	7.4
BOD	mg/L	20	4.5	4.3	4.5	4.3	3.3	3.3	15.2	14.3
COD	mg/L	-	14.8	14.1	14.8	14.1	11.0	11.0	50.2	47.2
Nitrate	mg/L	0.06	7.9	9.1	5.6	6.5	3.8	5.9	1.5	1.8
Phosphate	mg/L	0.015	1.0	0.8	0.9	1.0	0.4	0.6	1.1	0.9
Fecal coliform	jml/100 ml	-	5,735.0	5,796.3	3,821.3	2,007.5	6,830.0	4,228.8	1,781.3	1,287.5

* PP (2021) in Appendix VIII; HT=High tide; LT= Low T

3.2.The pollution status of the Belawan Estuary.

Based on the results of various water quality index calculations, it was shown that, spatially and temporally, the Belawan Estuary falls within the categories of moderate to heavy pollution (Figure 2). Both the PI and the MMWQI indices indicated the same status, classifying the Belawan Estuary as moderately polluted. However, the CCME method categorized it as heavily polluted. This discrepancy arises due to the different sensitivities of each method (CCME, 2017; Uddin *et al.*, 2021). Some experts argue that the CCME method is more sensitive because it includes correction factors in the calculation (F3), making it the most responsive to water quality dynamics (Romdania *et al.*, 2018).

Spatially, St7–8 is considered "worse" compared to other locations. This is attributed to the main source of pollution in the Belawan Estuary, the Terjun River, which passes between Stations 7 and 8. The Terjun River flows through the Terjun Landfill and residential areas in western Medan. Meanwhile, Stations 1 and 2 are closer to the sea, enabling the pollutants to be "diluted" by seawater, especially during high tides. Temporally, it was observed that the water quality was "slightly worse" during the full moon and new moon phases than during the last and first quarter phases. This is suspected to be due to higher levels of coliform bacteria during the full moon and new moon.

The high coliform bacterial levels were likely due to sewage (particularly human feces) originating from settlements in Belawan. During high tides (full moon and new moon phases), sewage is dispersed throughout the Belawan Estuary. Overall, estuaries in Indonesia are classified as moderately to heavily polluted. The Jakarta Bay Estuary shows mild-to-heavy pollution (DLH, 2022; 2023). The Tangerang Bay Estuary exhibits moderate-to-heavy pollution (Gumelar *et al.*, 2017; Prismayanti *et al.*, 2021). Water in Semarang Estuary is heavily polluted (Haeruddin *et al.*, 2019). The Cirebon City Estuary (West Java) also experiences mild-to-moderate pollution (Hidayah *et al.*, 2021).

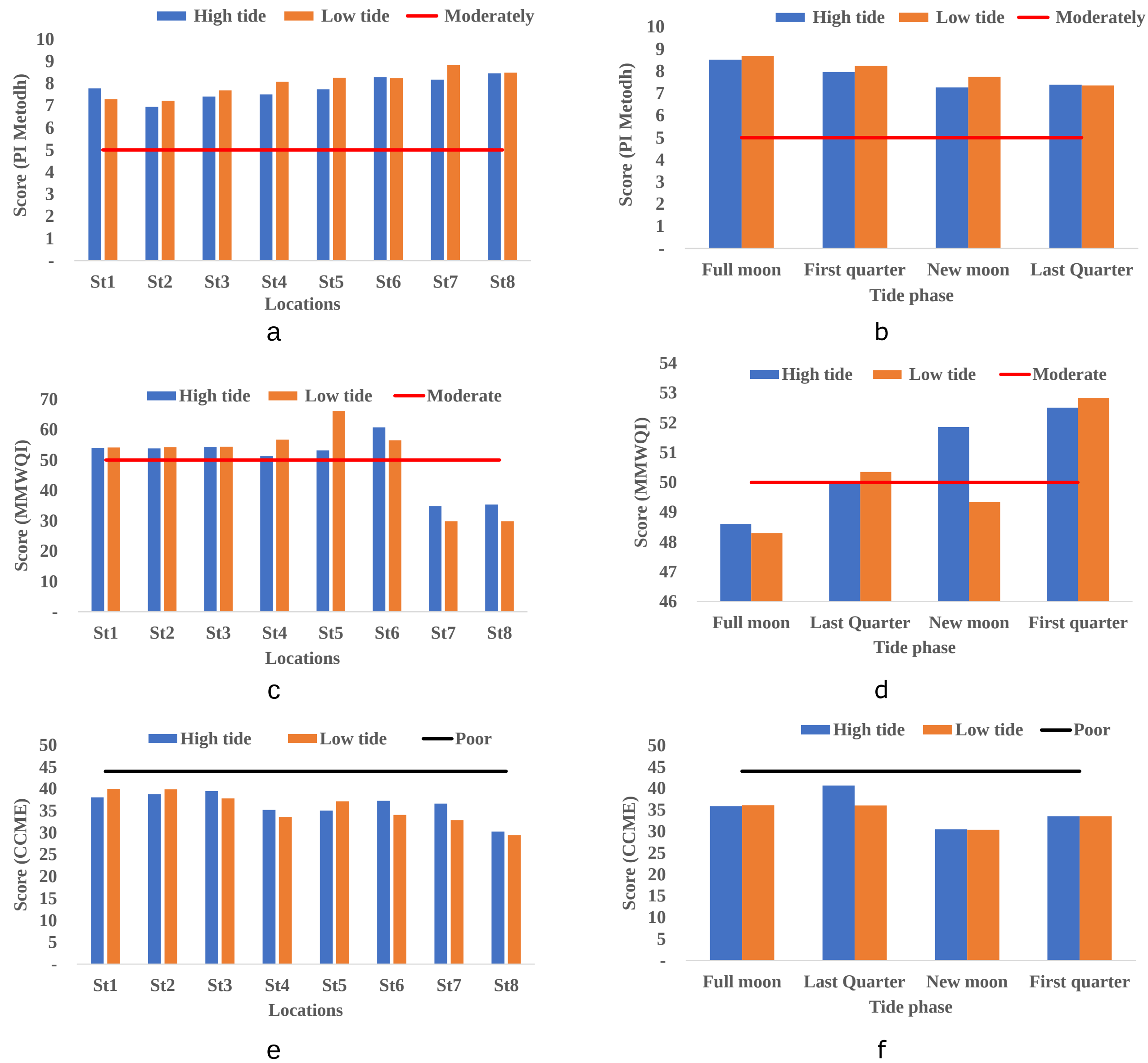

Figure 2. Graph of pollution status of Belawan estuary waters spatially (left) and temporal (right): (a-b) Pollution's index metod; (c-d) MMWQI metod; (d-e) CCME Method

4. Conclusion

Spatially and temporally, the Belawan Estuary falls within the category of moderate to heavy pollution. The main source of pollution in the Belawan Estuary is urban activities, primarily the Terjun Landfill. Nutrients and coliform bacteria were the main water quality parameters contributing to pollution in the Belawan Estuary.

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