Jurnal Rekayasa Kimia dan Lingkungan
(Journal of Chemical Engineering and Environment)
Volume 17, Number 1, Page 64 – 72, January -June, 2022
ISSN 1412-5064, e-ISSN 2356-1661
https:// 10.23955/rkl.v17i1.25155

Using Pollution Index to determine water quality in Banda Aceh waters, Indonesia

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Article History
Received: 9 March 2022; Received in Revision: 30 April 2022; Accepted: 12 May 2022

Abstract

The northern waters of Banda Aceh are connected with the Strait of Malacca, the Andaman Sea, and the Indian Ocean thus making the study of water quality parameters in this region is important for enviromental management. In this study, water quality parameters are measured spatially and continued with assessing the pollution index. The results can be helpful for development planning and coastal pollution mitigation in Banda Aceh. The data was collected from 21 seawater samples from 11 stations representing the water of Banda Aceh in 10-11 September 2019. VanDorn bottles were used to store the seawater samples for laboratory analysis. Several parameters such as temperature, salinity, and pH were measured in situ, while other parameters were tested in the laboratory. Lead was detected exceeding the threshold at several stations with the highest value of 0.1512 mg/L at station 1, however other heavy metal parameters showed values below the minimum value limit detection of the instrument, indicating a small potential for heavy metal contamination in the study area. The pollution index (PI) indicates the potential for water pollution dominated by nitrate and phosphate with a value that exceeds the water quality standard. The indications are shown from the high aquaculture and anthropogenic activities around the coast of Banda Aceh.

Keywords: Ammonia, Banda Aceh, nitrate, pollutant, surfactants, water quality

1. Introduction

The hydrography, morphology, and ecology of coastal regions are all highly affected by interactions between land and ocean (Short and Jackson, 2013). These interactions influence the sensitivity and vulnerability of the coastal areas to environmental changes, in addition to the high human population factor (Hamuna and Wanimbo, 2021; Lu et al., 2018)). Therefore, an analysis of water quality needs to be considered in developing fisheries and marine activities such as fishing areas, transportation, and tourism routes (Badriani, 2017; Doan et al., 2019; Kamizoulis and Saliba, 2004; Tanjung et al., 2019b; Varol, 2020).

Pollution from anthropogenic waste can affect water quality, which is an important issue and needs immediate attention (Hegazy et al., 2020; Mahabeer and Tekere, 2021; Swain et al., 2021). Reliable information on the quality of coastal waters can be used to identify sources of pollution, determine the status of water quality, and control water pollution in the coastal water, in particular, runoff from land (Saraswati et al., 2019; Ustaoğlu et al., 2020; Wu et al., 2018). Water quality assessments are mainly carried out using the water quality index (Dunca, 2018).

Located at the northern tip of Sumatra, Banda Aceh is the provincial capital and has intensive urban activities. The sea waters of Banda Aceh adjacent to the Andaman Sea, the Malacca Strait, and the Indian Ocean make the oceanographic conditions in these waters quite dynamic (Rizal et al., 2012) There are also potential threats to seawater conditions influenced by various urban activities in Banda Aceh city that potentially cause water pollution, such as domestic sewage, fish farms, and river runoff (Luhur et al., 2016; Syamsuddin et al., 2012). Therefore, the water quality study in the coastal area of Banda Aceh is crucial for future management. However, the previous few studies (Ondara et al., 2021, 2020) only emphasized the value and spatial distribution of the seawater parameters measured in the waters of Banda Aceh; Thus, the current status of pollution in

Banda Aceh Remains Unclear. This paper examined the water quality and Pollution Index (PI) to analyze the water conditions in the coastal area of Banda Aceh City. The results of the PI analysis provide information on environmental management and maintenance of water quality from the causes of polluting compounds (Badriani, 2017; Tanjung et al., 2019a). The study results are expected to be used as a basis for decision-making and policies for potential regional development and coastal pollution mitigation in Banda Aceh.

2. Methodology

2.1. Study Area

This research was conducted in the northern waters of Banda Aceh on 10 - 11 September 2019. Seawater sampling was carried out at 11 stations representing the northern waters of Banda Aceh (Figure 1). Station 1 is located close to the water flow with fish cages and is connected to a water canal with the community's fishponds. The sea waters around station 3 have an inlet connected to the mangrove area and community ponds. Station 5 is adjacent to the mouth of the Krueng Aceh River, which is the main river that crosses the city of Banda Aceh.

In the area near the estuary on the Krueng Aceh River, there are various fishing boat activities, including docking and ship repair activities. Station 6 is adjacent to the primary and largest port in Aceh province, namely Lampulo Port. This port is the main docking area for traditional fishing vessels, generally measuring > 5 GT, which operate around the northern waters of Sumatra, specifically operating in the Malacca Strait and the Indian Ocean. Station 7 is located near the swamp area and community's fishponds, while station 9 is outside the mouth of the Lamnyong estuary.

2.2. Data sampling

Seawater was sampled using a Van Dorn water sampling device with a volume of 4.2 liters. The Van Dorn bottle was submerged to three meters, then the ballast (messenger) was lowered to cover the water in the bottle. Five liters of water from each station were put in sample bottles and marked according to the station number. Several parameters, namely dissolved oxygen, pH, temperature, and salinity, were tested in situ. Water samples were taken to the Baristand Banda Aceh the same day after data collection. Baristand Banda Aceh is a testing laboratory with national accreditation by the National Accreditation Committee (KAN) and LS-Pro. The analytical method for each parameter tested can be seen in Table 1. The data were analyzed descriptively by comparing the sample result with the seawater threshold value determined by the Minister of Environment Decree Number 51 (KLH, 2004) Annex 3 regarding quality standards for marine biota.

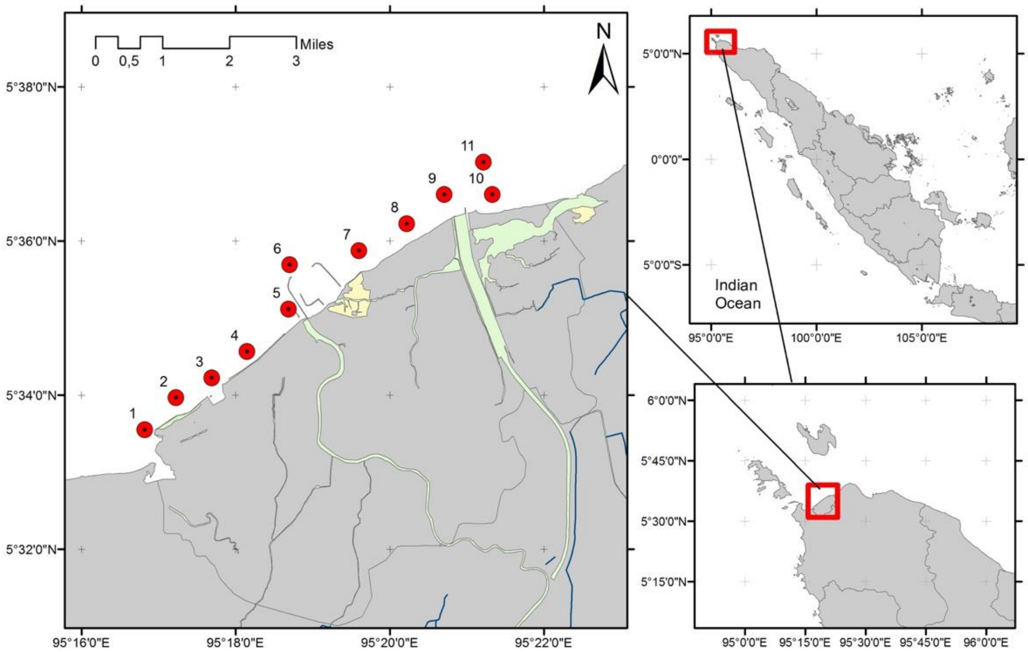

Figure 1. Sampling stations along coastal waters of Banda Aceh.

Table 1. Parameters of water quality and analytical methods.

Parameter	Method	Units	Standard
TSS	Gravimetry	mg/l	20
Total Ammonia	SNI 066989.30.2005	mg/l	0.3
Surfactants	SNI 6989.51.2005	mg/l	1
BOD5	SNI 6989.72:2009	mg/l	20
Dissolved Oxygen	DO Meter	mg/l	> 5
pH	*In situ*		*7-8.5*
Water temperature	*In situ*	*°C*	*28-30*
Salinity	*In situ*	*ppt*	*33-34*
Mercury	AAS/ Shimadzu - AA7000	mg/l	0.001
Chromium Hexavalent	AAS/ Shimadzu - AA7000	mg/l	0.005
Zinc	AAS/ Shimadzu - AA7000	mg/l	0.05
Nickel	AAS/ Shimadzu - AA7000	mg/l	0.05
Lead	AAS/ Shimadzu - AA7000	mg/l	0.008
Arsen	AAS/ Shimadzu - AA7000	mg/l	0.012
Copper	AAS/ Shimadzu - AA7000	mg/l	0.008
Cadmium	AAS/ Shimadzu - AA7000	mg/l	0.001
Sulfide	Spectrophotometry/ Shimadzu UV Vis 2700	mg/l	0.01
Phosphate	Spectrophotometry/ Shimadzu UV Vis 2700	mg/l	0.015
Total Phenol	Spectrophotometry/ Shimadzu UV Vis 2700	mg/l	0.002
Cyanide	Spectrophotometry/ Shimadzu UV Vis 2700	mg/l	0.5
Nitrate	Spectrophotometry/ Shimadzu UV Vis 2700	mg/l	0.008

2.3. Water Pollution Index

The Pollution Index (PI) method is commonly used to determine water quality status (Liu et al., 2010; Zhang, 2017). The PI method provides reliable information related to managing the aquatic environment and monitors the presence of pollutant compounds (Hossain and Patra, 2020). The calculation of the PI value is obtained based on the Decree of the Minister of the Environment Number 51 of 2004, using the Nemerow-Sumitommo equation as follow (L. Nemerow and Sumitomo, 1970):

$$PI_j = \sqrt{\frac{(C_i/L_{ij})_m{}^2 + (C_i/L_{ij})_R{}^2}{2}} \quad (1)$$

Remark:

- Lij = concentration of water quality parameters listed in the water quality standard (j)
- Ci = concentration of water quality parameters survey results
- PIj = Pollution Index for designation (j)
- $(Ci/Lij)_M$ = maximum value for Ci / Lij
- $(Ci/Lij)_R$ = average value for Ci/Lij

The water quality status was determined based on the PI standard referring to the Decree of the Minister of Environment No: 115 Year 2003 on Determination of Water Quality Status as follows:

- $0 \le PIj \le 1$: good quality
- $1 \le PIj \le 5$: lightly polluted
- $5 \le PIj \le 10$: moderately polluted
- $PIj > 10$: heavily polluted

3. Results and Discussion

3.1. Water quality

The results of laboratory analysis of seawater quality in Banda Aceh City's waters (Station 1 - 11), along with the seawater quality standard threshold values for biota, are presented in Table 2. Several parameters such as phenol, oil layer, and several parameters of heavy metals such as Hg, Cr, As, Cd, Cu, Zn, and Ni, cannot be detected by the tool. For statistical analysis purposes, the parameters with a value below the detection threshold were determined based on half of the tool's detection limit value.

Temperature and salinity are important physical parameters in coastal water environments. Temperature and salinity data were collected in situ in the surface layer. Changes in water temperature will interfere with other aquatic physical and chemical parameters and indirectly affect marine biota (Xie et al., 2015). The sea surface temperature (SST) ranged from 29.8-30 °C, and salinity ranged from 15-30 ppt, thus indicating natural and ideal conditions for marine biota. Salinity value in Banda Aceh waters did not show any variation, except for some locations close to the rivers, namely stations 1, 5, and 9, which have less saline water. In general, the salinity measured from station 1-11 were below standard value, thus indicating that the coastal waters of Banda Aceh are influenced by land from the runoff process.

Table 2. The results of water quality measurements in Banda Aceh waters.

Parameters	Station						
	1	2	3	4	5	6	7
TSS	8	8	8	10	10	14	14
Total Ammonia	**1.1**	0.002	0.08	0.01	0.02	0.01	*0.0005*
Surfactants	0.016	0.023	*0.005*	*0.005*	0.015	0.012	0.042
BOD5	0.765	1.5	1.7	1.3	1	2.1	1.9
Dissolved Oxygen	7.95	8.05	8.15	8	8	8.15	8.2
pH	7.97	7.81	7.85	7.89	7.84	7.87	7.87
Temperature	30	30	29.9	30	30.3	30	30
Salinity	25	30	29	29	28	29	30
Mercury	*0.00025*	*0.00025*	*0.00025*	*0.00025*	*0.00025*	*0.00025*	*0.00025*
Cr VI	*0.00005*	*0.00005*	*0.00005*	*0.00005*	*0.00005*	*0.00005*	*0.00005*
Zinc	*0.00005*	*0.00005*	*0.00005*	*0.00005*	*0.00005*	*0.00005*	*0.00005*
Nickel	*0.0005*	*0.0005*	*0.0005*	*0.0005*	*0.0005*	*0.0005*	*0.0005*
Lead	**0.1512**	**0.0915**	**0.0319**	**0.012**	*0.0005*	*0.0005*	*0.0005*
Arsen	*0.0001*	*0.0001*	*0.0001*	*0.0001*	*0.0001*	*0.0001*	*0.0001*
Copper	*0.0004*	*0.0004*	*0.0004*	*0.0004*	*0.0004*	*0.0004*	*0.0004*
Cadmium	*0.0002*	*0.0002*	*0.0002*	*0.0002*	*0.0002*	*0.0002*	*0.0002*
Sulfide	*0.0005*	*0.0005*	*0.0005*	*0.0005*	0.001	*0.0005*	0.002
Phosphate	**0.19**	**0.46**	**0.27**	**0.35**	**0.345**	**0.32**	**0.38**
Total Phenol	*0.0005*	*0.0005*	**0.014**	*0.0005*	*0.0005*	*0.0005*	*0.0005*
Cyanide	0.0005	0.001	*0.0005*	*0.0005*	*0.0005*	*0.0005*	0.001
Nitrate	**0.2**	**0.2**	**0.3**	**0.4**	**0.3**	**0.3**	**0.5**

Next table

Parameters	Station			
	8	9	10	11
TSS	6	8	12	6
Total Ammonia	*0.0005*	0.01	0.02	0.01
Surfactants	*0.005*	0.016	*0.005*	0.011
BOD5	1.8	2.3	2.1	1.5
Dissolved Oxygen	7.95	7.85	8	8.1
pH	7.93	7.96	7.95	7.95
Temperature	29.8	29.8	29.8	29.8
Salinity	29	28	29	29
Mercury	*0.00025*	*0.00025*	*0.00025*	*0.00025*
Cr VI	*0.00005*	*0.00005*	*0.00005*	*0.00005*
Zinc	*0.00005*	*0.00005*	*0.00005*	*0.00005*
Nickel	*0.0005*	*0.0005*	*0.0005*	*0.0005*
Lead	*0.0005*	*0.0005*	*0.0005*	*0.0005*
Arsen	*0.0001*	*0.0001*	*0.0001*	*0.0001*
Copper	*0.0004*	*0.0004*	*0.0004*	*0.0004*
Cadmium	*0.0002*	*0.0002*	*0.0002*	*0.0002*
Sulfide	0.0005	0.002	0.001	*0.0005*
Phosphate	**0.305**	**0.22**	**0.3**	**0.35**
Total Phenol	*0.0005*	*0.0005*	*0.0005*	*0.0005*
Cyanide	*0.0005*	*0.0005*	*0.0005*	*0.0005*
Nitrate	**0.3**	**0.3**	**0.3**	**0.3**

Description: Values marked in italics indicates that the parameters cannot be detected by the tool. The value was obtained from half value of the tool test limit. The values marked in bold have a value exceeding the tolerance limit.

Biological Oxygen Demand (BOD) levels ranged from 0.765-2.3 mg.L-1; this value is below the quality standard threshold for marine biota (20 mg.L-1). Higher BOD levels were found around the estuary, especially Stations 6 and 9, adjacent to Lampulo Port and Krueng Lamnyong estuaries, respectively. The situation might be related to the relatively large presence of the decomposing microorganisms in these areas, which requires oxygen to carry out the decomposition or aerobic decomposition of organic material. Furthermore, high BOD presence in river estuaries can also be caused by waste and organic material from human activities due to the high human activity around the river flows (Amira et al., 2021; Susilowati et al., 2018).

Dissolved Oxygen (DO) is an essential parameter in the waters because it is closely related to the photosynthetic mechanism by autotrophic biota. Oxygen in the waters is derived from air diffusion and photosynthesis by the phosphorylation process (Kamer and Stein, 2003). Several previous studies indicated that dissolved oxygen levels fluctuate depending on the season and the influence of land (Chi et al., 2020; Guo et al., 2019). DO levels in Banda Aceh waters ranged from 7.85 to 8.2 mg.L-1. Referring to the Decree of the State Minister for the Environment(KLH, 2004), the DO level allowed for biota and marine tourism is > 5 mg.L-1. The high DO levels are strongly related to the coast and upper layer conditions which remain close to 100% due to turbulence, waves, and photosynthesis (EPA, 2001; Marks and Pytel, 2011).

Ammonia levels were found within the range of 0.001 to 1.1 mg.L-1. Station 1, in the Ulee Lheue area, has the highest value and exceeds the standard quality level for marine life (0.3 mg.L-1). The existence of a floating cage around station 1 and the water flow connected to the aquaculture area was thought to contribute to the high levels of ammonia in the surrounding areas. Intensive aquaculture with high stocking density and high feeding frequency encourages sewage accumulation very quickly (Wong et al., 2018).

Nitrate and phosphate show levels that have passed marine biota quality standards: 0.008 mg.L-1 for nitrate and 0.015 mg.L-1 for phosphate. This condition could have implications for the potential of algae bloom and may cause hypoxic conditions (Karthik et al., 2020). The high levels of nitrate and phosphate in the northern waters of Banda Aceh might be influenced by land input such as household waste that increased levels of nitrate and phosphate in the waters (Howarth et al., 2002; Paudel et al., 2019). In particular, the highest phosphates were found around station 1, specifically at the Ulee Lheue estuary. Hydrooceanographic factors such as currents also affect the distribution of nitrate and phosphate concentrations around the northern waters of Banda Aceh (Setiawan et al., 2018), in addition to turbulence and resuspension, which causes nutrients in the sediment to be lifted into the water column (Qin and Shen, 2019; Utami et al., 2016).

The presence of surfactants in Banda Aceh waters is below the specified quality standard (1 mg.L-1). Furthermore, the value of the degree of acidity (pH) in Banda Aceh waters ranges from 7.81-7.97, which still meets the quality standard value based on the 2004 Minister of Environment Regulation. Seawater has a substantial buffering capacity to prevent changes in the degree of acidity (Bugica et al., 2020). However, on a small scale, changes in pH can disrupt the buffer system and cause changes and imbalances in CO2 levels that can endanger marine life (Mosley et al., 2010).

Meanwhile, sulfide, cyanide, and oil parameters were not found in the study area, shown by the levels of these parameters that were smaller than the detection limit of the test equipment. Phenolics were only found at station 3 with levels of 0.014 mg.L-1, thus exceeding the quality standard of 0.002 mg.L-1. Phenols in waters are generally found due to industrial waste disposal and fuel from ships (Mbunde et al., 2018; Winarno et al., 2010). The condition in station 3, located between Ulee Lheue and Lampulo, is possible due to the high activity and traffic of fishing boats.

The presence of heavy metals in waters needs to be considered seriously. Tests carried out on heavy metals Hg, Cr + 6, As, Cd, Cu, Zn, and Ni showed levels below the test equipment's detection limit, which indicated that these heavy metals did not contaminate Banda Aceh waters. High levels of lead (Pb) were found in stations 1, 2, 3, and 4, indicating lead (Pb) contamination. The four stations, especially around the waters between Ulee Lheue and Gampong Jawa (station 1 - 4), have lead (Pb) levels that exceeded the marine biota's quality standard of 0.008 mg.L-1. Excess Pb level in station 3 is caused by pollution by ship activity and traffic, which is explained by the high phenol concentration (Isakson et al., 2001).

3.2. Pollution Index (PI)

The pollution index (PI) is determined by considering the quality standard values of the parameters set by KLHK. The water quality status of the coastal waters of Banda Aceh shows that the lowest PI value is 5.7342 found at station 1, and the highest pollution index is 7.0951 found at station 7. Based on the PI, Banda Aceh waters, represented by 11 stations along 6 nm coastal waters, are moderately polluted (Figure 2).

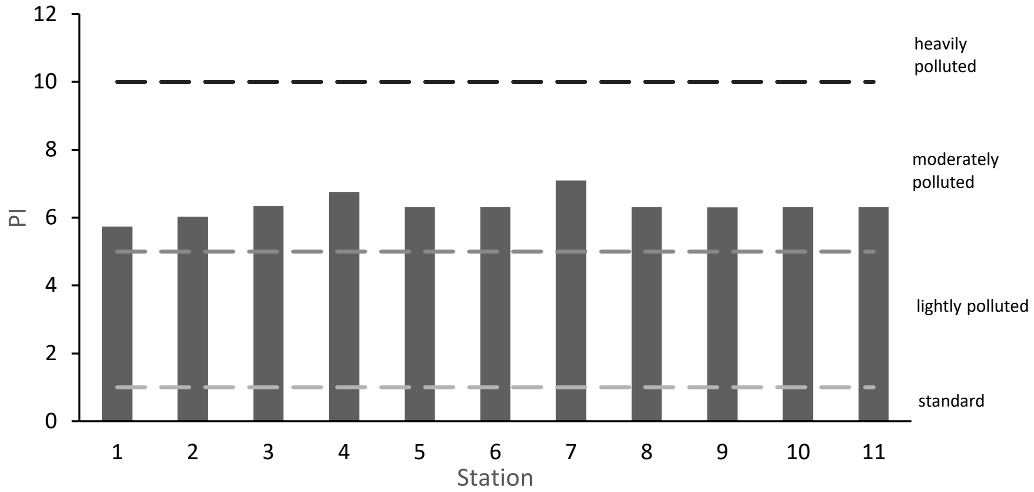

Figure 2. The water pollution index in coastal waters of Banda Aceh.

The result can be allegedly derived from several parameters that are not in accordance with the quality standards set by (KLH, 2004), including phosphate and nitrate, which exceed the quality standard at all stations, lead (Pb) exceeds quality standard at stations 1-4, while Pb was detected relatively high at station 1. In particular, the use of the Nemerow-Sumitomo PI equation seems to give a fairly large portion of $(Ci/Lij)_M$ in the calculation, which in this study was generated mainly by nitrate parameter, which led to an increase in the pollution index for the entire coastal waters of Banda Aceh.

Several water parameters in the coastal waters of Banda Aceh have values below the tool's detection limit. These parameters were not detected by the tool, which could be interpreted as quite good for water conditions. In general, no heavy metals were detected in the coastal waters of Banda Aceh, except for Pb at four stations. This result can give an initial assumption that there is no severe pollution, specifically for heavy metal contamination, detected in the coastal waters of Banda Aceh. Furthermore, special attention is required to control pollution conditions in the coastal waters of Banda Aceh, especially nitrate and phosphate. Likewise, managers also need to focus on locations characterized by being polluted by aquaculture or pond activities and managing inland water inputs to have minimum levels of pollutants.

4. Conclusion

Based on the physio-chemical parameters analyzed in the Banda Aceh coastal area, some water quality parameters exceed the threshold set by the Minister of the Environment. PI analysis shows that the effect of nitrate and phosphate is quite influential on all stations categorizing the waters along the coast of Banda Aceh as moderately polluted. The test results of heavy metal parameters indicate that lead (Pb) has levels that exceed the quality standard only around Ulee Lheue waters.

Acknowledgement

This study was financially supported by the Ministry of Marine Affairs and Fisheries through the 2019 DIPA research fund. The authors would like to thank Panglima Laot Ulee Lhee for the assistance during data collection.

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