Evaluation of coastal pollution in Banda Aceh based on BOD$_5$ and DO approach

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Abstract. The demand for preserving the aquatic environment is a top priority for the Indonesian government. The Banda Aceh coast has experienced anthropogenic developments since the 2004 tsunami hit. During the preliminary investigation in 2017, it indicated that the Banda Aceh coast had been contaminated. Here, we investigated water quality in Banda Aceh coast has been conducted during 2018-2019. We employed the Winkler titration for determining Biological Oxygen Demand (BOD$_5$) and Dissolved Oxygen (DO). Furthermore, we generated spatial analysis to show the distribution of BOD$_5$ and DO around the Banda Aceh coast. As a result, BOD$_5$ has been decreased with the value of 1.33 mg/L. Interestingly, the increased DO value of 1.48 mg/L indicated the presence of autotroph biota producing an oxygen atom during 2018-2019. A contrary influence of BOD$_5$ and DO on NO$_3$- was identified, which approximately 50% concentration of nutrient determined by oxygen availability in 2018, while it was less than 5% for the 2019 survey. In conclusion, we suspect that the Banda Aceh coast is categorized as polluted waters for marine biota and tourism.

1. Introduction

A significant decline in the world's biological diversity has been attributed to human activities. According to one estimate, human activities could have accelerated present extinction rates to a level 1,000 to 10,000 times the natural rate [1]. Moreover, marine life is endangered by various threats, including overfishing, and harvesting, dumping of waste, pollution, alien species, land reclamation, dredging, and global warming [2-5]. In addition, introducing human activities into the marine environment, including estuaries, may result in a loss of marine life or fish, hazards to human health, and impairment of aquatic activities such as fishing or other legitimate uses of the sea [6]. Nevertheless, by adding pollutants to the watershed, the ecosystem's overall composition will be altered. A significant amount of biodegradable and stable compounds from soil can interact negatively with coastal waters [7]. It is expected that 25 to 30 percent of these substances end up in the ocean every year. Some of these substances break down while others are persistent. Their cumulative impact on the coastal marine environment could be sufficiently toxic over time [8-9].

Salty waters of a marine environment degrade organic matter at a slower rate than freshwater [10]. Pollution control authorities have classified standards based on their "best-designated uses" in coastal areas [11]. The biochemical oxygen demand (BOD$_5$) determines the best rate of pollution abatement and treatment schemes. BOD$_5$ is greatly affected by pH, osmotic conditions, temperature, and the
amount of incubation time [12]. To date, Irham and his co-workers have surveyed the estuary area of Krueng Cut in 2017 [13]. However, given the rising amount of anthropogenic activity, a continuous evaluation must be conducted to mitigate ecosystem damage sooner. Here, we evaluate the coastal pollution surrounding the Banda Aceh area based on BOD$_5$ and DO approaches together with nitrate concentration as a part of water quality.

2. Material and Methods
The study has been carried out around Banda Aceh and Aceh Besar during 2018-2019. An analysis of BOD$_5$, DO and nitrate were conducted at the Research and Industrial Standardization Institute, Banda Aceh. The aquatic environment is one of the factors we consider when designing sampling sites. Additionally, the samplings had been conducted during low tidal conditions so that the land-sourced contaminant was considered. However, the comparison between the two years of observation can equally be made because the samplings were conducted during September for each year whereby the relatively high intensity of rainfall was considered espousing the land-sourced pollutant intake in the estuaries. Different sampling points over the two years of observation had been made; in 2018, the sampling site was parallel along the coastline, while in 2019, the sampling was focused on the city centre of Banda Aceh (Figure 1).

![Figure 1. Study area and sampling stations.](image)

2.1. Sample collections
A sample bottle containing 250 mL of water was used for taking water samples from 3 depths. An empty sample bottle was immediately immersed in water with its back facing the flow rate. The bottles were kept in the freezer until further analysis. In addition, we evaluated DO based on both in situ and ex situ approaches [14].

2.2. Analysis of BOD$_5$
In the absence of light, samples were incubated at 20°C for five days. Moreover, the samples were tested according to the protocol of Winkler Titration [14]. On the other hand, DO Winkler titration was measured without incubation step.
2.3. Nutrient and Correlation Analyses
The collected water samples which previously were prepared using four drops of concentrated H₂SO₄ were distilled using nitrocellulose membrane filter (pore size of 0.45 μm, diameter 47 mm). It was then cooled in a fridge. The NO₃⁻-N analysis was performed using a spectrophotometer (Genesis 10s UV-VIS) with wavelength of 410 nm with limit detection of 0.1-2 mg/L. In this analysis, brucine was also identified [15].

Knowing that the alteration in oxygen-based parameters is going to influence on nutrient states. We assessed the correlation between BOD₅-DO and nitrate using a linear regression method [16]. In this case, the BOD₅ and DO become the dependent variables and nitrate becomes the independent variable.

3. Result and Discussion
The characteristics of BOD₅ and DO in the Banda Aceh and Aceh Besar areas are shown in Figure 2. In 2018, the higher concentration of BOD₅ and DO at all stations except #8-9 confirmed coastal pollution in the area. Surprisingly, as stations #8-9 were evaluated to have higher DO concentration than BOD₅, it revealed the water condition is much less polluted than other areas. We suspect that anthropogenic activities around the sampling site may be responsible for increasing BOD₅ concentration in 2018 (Figure 2). During this period, the levels of BOD₅ and DO were tremendously lower compared to the quality standard established by the Ministry of Environment No. 51 in 2004 whereby the required concentration of BOD₅ and DO is 20 mg/L and >5 mg/L, respectively.

![Figure 2. The profiles of BOD₅ and DO in 2018.](image)

Further analysis in 2019 showed the lowest concentration of BOD₅ was detected at sampling stations #15-21 and #23-26, while sampling stations #6, 9, and 10 have the highest concentration. Interestingly, all sampling stations were evaluated to have a high concentration of DO. Overall, the results also revealed that the water is less polluted in 2019 than in 2018 (Figure 3). Unlike the previous survey result, the concentration of DO was getting higher and generally in accordance with the quality standard established by the Ministry of Environment. In contrast, the concentration of BOD₅ declined considerably and it was tremendously lower compared to the required BOD₅ concentration to support the life of marine biota and tourism.
Figure 3. The profiles of BOD$_5$ and DO in 2019.

With detailed analysis, we also assessed the influence of BOD$_5$ and DO on NO$_3^-$ concentrations. In aquatic ecosystems, oxygen is the most significant parameter as the water quality indicator because of its role in the oxidation and reduction of organic and inorganic compounds, resulting in nutrient availability in the waters [17]. On the other hand, the BOD$_5$ is defined as the oxygen demand needed by organism to disintegrate organic compounds within the aerobic condition [18]. Thus, the BOD$_5$ and DO should play a significant role in controlling the nutrient availability within the water bodies [19]. We report herein the correlation analysis between BOD$_5$, DO, and NO$_3^-$. The analyses are shown in Figure 4 and 5. In this case, NO$_3^-$ is the dependent variable, while BOD$_5$ and DO are the independent variables.

Figure 4. Correlations of DO vs NO$_3^-$ and BOD$_5$ vs NO$_3^-$ for 2018 data.
Figure 5. Correlations of DO vs NO$_3^-$ and BOD$_5$ vs NO$_3^-$ for 2019 data.

In 2018, concentration of NO$_3^-$ ranged from 1.4 up to 2.3 mg/L. DO and BOD$_5$ are most likely to reflect the same influence on NO$_3^-$ concentration in the water (Figure 4). The relatively low level of DO results in the sufficiently high concentration of NO$_3^-$. Even though many factors control the nutrient availability in water, the correlation between DO and NO$_3^-$ shows a good relationship with the R$^2$ value of 0.57. It means that almost around 57% of the DO level determines the nutrient (NO$_3^-$) concentration in the Banda Aceh waters. In comparison, as much as 47% of the BOD$_5$ state determines the NO$_3^-$ concentration. These results allow that around 50% of the NO$_3^-$ level is influenced by other factors, including land and sea provenance nutrient intake.

The contrast result was found in the 2019 survey whereby the concentration of DO increase and the BOD$_5$ decreased compared to the previous measurement (Figure 5). These conditions probably induce a lower concentration of nutrients due to the imbalanced oxygen condition in the water. Still, the result shows a common condition in which either DO or BOD$_5$ does not reflect the state of NO$_3^-$. The R$^2$ values obtained from those two assessments are too low. Only less than 5% of DO-BOD$_5$ concentration can determine the low NO$_3^-$ concentration (ranging from 0.2-0.5 mg/L). Thus, we can conclude that other factors influenced the intake of nutrients during 2019 out of BOD$_5$-DO controls.

4. Conclusion
The higher concentration of BOD$_5$ at all stations except #8-9 confirmed the presence of coastal pollution. However, stations #8-9 were analysed to have higher DO concentrations than BOD$_5$ suggested that water condition is much less polluted than other areas in 2018. The results indicated the anthropogenic activities around the sampling site might be responsible for the increase in BOD$_5$ concentration in 2018. On the other hand, the lowest concentration of BOD$_5$ was detected at sampling stations #15-21 and #23-26, while sampling stations #6, 9, and 10 have the highest concentration of them in 2019. Generally, except for the DO concentrations observed in 2019, the remnant BOD$_5$-DO states are tremendously lower than the quality standard established by the Ministry of Environment in 2004 for marine biota and tourism. The results also revealed that the water is less polluted in 2018 than 2019, while the higher concentration of DO was detected in 2019. The influence of BOD$_5$-DO on nutrient concentration is
tremendously contrasting over the two years of observation whereby in 2018, the nutrient tended to be controlled by BOD$_5$ and DO states while in 2019, the other factors inducing nutrient were predominant.

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