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# Water Quality Status of Mangrove Ecosystem in Bedono, Sayung, Demak, Central Java

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**ABSTRACT**

Mangrove ecosystems have many functions for coastal areas, including ecological, social, and economic services. These functions have a systemic impact on the environment of other coastal ecosystems and human life. The mangrove ecosystem covering an area of 197.92 ha in Bedono, Demak Regency, Central Java was threatened due to the wave abrasion and high tides. Some parts of Bedono Village had become inundated and flooded permanently, zink as part of the ocean. This research was conducted to quantify water pollution in the mangrove ecosystem of Bedono Village using the Storage and Retrieval (STORET) method and the pollution index (PI). The fieldwork was conducted June 2022, by collecting water samples for laboratory analysis tests and in-situ water quality measurement. The parameter of the water quality that exceeded threshold of the Government Regulation of the Republic of Indonesia Number 22 of 2021 are the dissolved oxygen (DO) ranges between 4.39-8.78 mg $L^{-1}$, BOD ranges between 30-32.4 mg $L^{-1}$, phosphate ranges between 0.063-0.074 mg $L^{-1}$, ammonia ranges between 0.148-0.48 mg $L^{-1}$, Cr ranges between 0.071-0.21 mg $L^{-1}$, and Pb ranges between 0.071-0.21 mg $L^{-1}$. Based on the STORET method, the water quality in the mangrove ecosystem was found to be in the category of moderately (-16, for harbor function) – heavily polluted (-80, for tourism and -90, marine biota), whereas based on the PI index it was lightly polluted (1.77-4.12, for harbor function) – moderately polluted (11.06-13.83for tourism, and 9.96-11.85, marine biota).

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## INTRODUCTION

Coastal areas are impacted by natural pressures such as sedimentation, erosion, abrasion, storms, tsunamis, and other pressures caused by anthropogenic factors such as the entry of pollution from settlements, agriculture, and industry (Dehghani & Karbassi 2015; Canning et al. 2023; Pandey et al. 2023).

Mangrove ecosystems also have a major role in coastal ecosystem function in reducing pollution levels, barrier abrasion, resisting seawater intrusion, and as a gathering place for biota because they are highly productive (Dehghani & Karbassi 2015; Erny and Jeriels 2019; Matatula et al. 2019). The Hara Protected Area in Iran consists of mangrove ecosystems, habitat

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for migratory birds, and other biotas such as reptile, fish, arthropods, and bivalves (Dehghani & Karbassi 2015). Mangrove plants, particularly *Avicennia marina* is a good bioaccumulator for heavy metals, as shown from the research ini Sirik Azini Creek, Iran (Parvaresh et al. 2011).

However, human activities have degraded the mangrove ecosystem over time (Zhou et al. 2023). The mangrove ecosystem is a typical ecosystem that lives on the coast or river estuaries continuously influenced by sea waters (Sjafrie 2016).

Mangrove ecosystems are part of the blue carbon ecosystem, along with swamps and seagrasses, which plays an important role in global carbon sequestration (Herr and Landis 2016). Blue carbon ecosystems are characterized by their ability to store large amounts of organic carbon in sediments over long periods (Taillardat et al. 2018).

The area of mangrove ecosystems is only 2% of the world and Indonesia contributed 23% (Dahuri 2001; Kordi 2012; Harris 2014). Mangrove ecosystems in Indonesia are thought to have experienced deforestation, especially for cultivation development, since the 1800s (Ilman et al. 2016). Activities such as reclamation and changes to the function of land into fishery ponds disrupt the function of the mangrove ecosystem (Eddy et al. 2021).

Demak Regency, located on the north coast of Java Island, has considerable mangrove potential. Based on data from the Demak Regency Environmental Service, in 2017, the total area of the mangrove ecosystem in Demak reached 13,960.5 ha, divided into 980.1 ha of areas with good vegetation and 12,980.4 ha of areas with sparse vegetation. Of this area 68.17 ha has experienced degradation (2010-2015); this is due to changes in land use (Irsadi 2019), the construction of ponds, and abrasion (Nurrohmah 2016).

Demak's increasing population and industrialization have resulted in land conversion changes and higher pollution levels. Massive and rapid urbanization places enormous strain on environmental carrying capacity and threatens ecosystem sustainability, particularly in South and East Asian developing or developed countries such as China (Zhang et al. 2020; Cai et al. 2021), Japan (Chao et al. 2020), India (Singh et al. 2021), Vietnam (Pham et al. 2021), Malaysia (Muhammad et al. 2020), and Indonesia (Irsadi et al. 2020; Soeprobowati et al. 2020), India (Singh et al. 2021), and Vietnam (Pham et al. 2021).

Bedono Village is located in Demak Regency which has the widest mangrove forest area in the Sayung District, with a mangrove ecosystem of 197.19 ha. The condition of the mangrove forests in Bedono has been damaged due to sea level rise, erosion, and land subsidence (Sihombing et al. 2017). The existence of reclamation activities for harbor construction in Semarang City has also affected seawater flow patterns, impacting the Bedono mangrove ecosystem (Apriyanti 2021). Since 1990s the development of industries, such as furniture, wood parquet, plastic, cardboard, pharmaceutical drug, car body parts, electronics, printing, garment, and batteries along with Semarang to Demak influences the water quality in the mangrove ecosystem. At the same time, the aquaculture fisheries had also reduced the mangrove ecosystem in Bedono. This study will calculate and assess the water quality in the Bedono mangrove ecosystem using the pollution index (PI) and STORET following the Minister of Environment Regulation No. 115 of 2003 regarding Guidelines for Determining Water Quality.

## MATERIAL AND METHODS

The research location is in Bedono Village, Sayung District, Demak Regency, Central Java, where the entire area is directly adjacent to the coastline on the north coast of Java. Demak is located at 60 55'36.9' S and 1100 29'05.1' E with an area of 739 ha. The mangrove area in Bedono Village has been designated as a conservation area by Regional Regulation of Demak Regency No. 6 of 2011 concerning Spatial Plans for Mangrove Forest Areas, which are natural forests planted with mangroves by the community to minimize the impact of abrasion. The geographical location of Bedono Village is in the north of Sayung District with the following

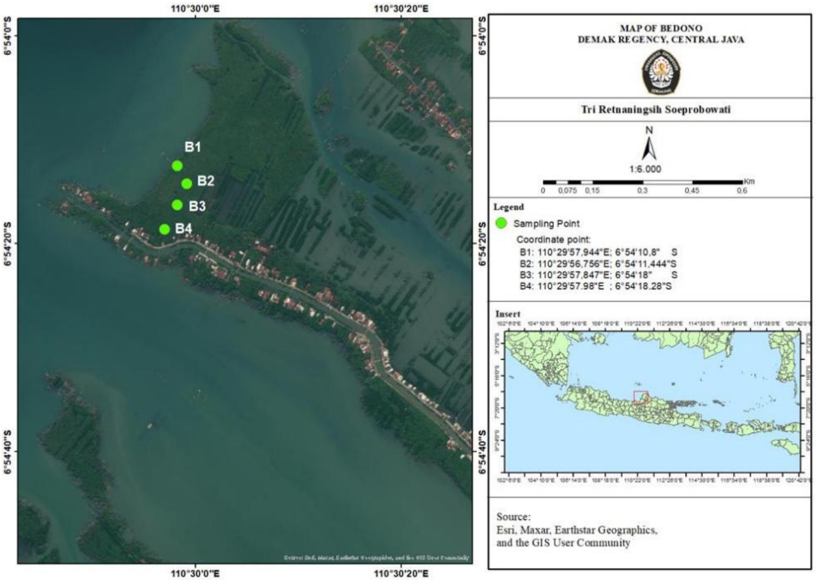


**Fig. 1.** Research sites in mangrove ecosystem of Bedono Village, Sayung, Demak, Cental Java

administrative boundaries: to the north, it is bordered by Timbulsloko Village, to the south by Sriwulan Village, to the east by Purwosari Village and Sidogemah Village and the west by the Java Sea.

The initial stage is the pre-survey stage which aimed to determine the research location and sampling sites. The next stage was fieldwork which was held on June 15, 2022. Fieldwork activities included in-situ measurement of water quality such as pH, salinity, dissolved oxygen (DO), conductivity, and turbidity. Water samples were collected for water quality analysis using the van Dorn water sampler, and these were filtered for nutrient and heavy metal analysis. Sampling was carried out at four research sites (Figure 1), with the selected sites 1 to 4 represent the condition of the Bedono mangrove ecosystem (Figure 2). The water taken was then placed into a 600 ml sample bottle and put into a cooler box for analysis at the Diponegoro University Environmental Engineering Laboratory.

The data of the physical and chemical parameters analysed were then compared with the quality standard criteria of Government Regulation no. 22 of 2021 concerning the Management of Water Quality and Control of Water Pollution. Determination of the water quality status of the Bedono Demak mangrove ecosystem was assessed using two methods, namely the Pollution Index (PI) and the STORET (Storage and Retrieval of water quality data system) method, which refers to the Regulation of the Minister of Environment of the Republic of Indonesia (RMoERI) No. 115/2003 concerning Guidelines for Determining Water Quality Status. Basically, STORET and PI are similar in determining the water quality status. STORET was developed and used in the USA, and Indonesia adopted it in line with PI. STORET determines the water quality status in general (based on the data from all sites), but the PI determines the pollution index of each site.

The STORET method, a technique that is often used in Indonesia in determining the status of water quality, is based on the value system of the US-EPA (United State-Environmental Protection Agency) to categorize water quality (Table 1). Through the STORET method, it can be determined which parameters meet or exceeded water quality standards by comparing water quality data with water quality standards adjusted for their designation to determine water quality status (Rintaka et al., 2019).

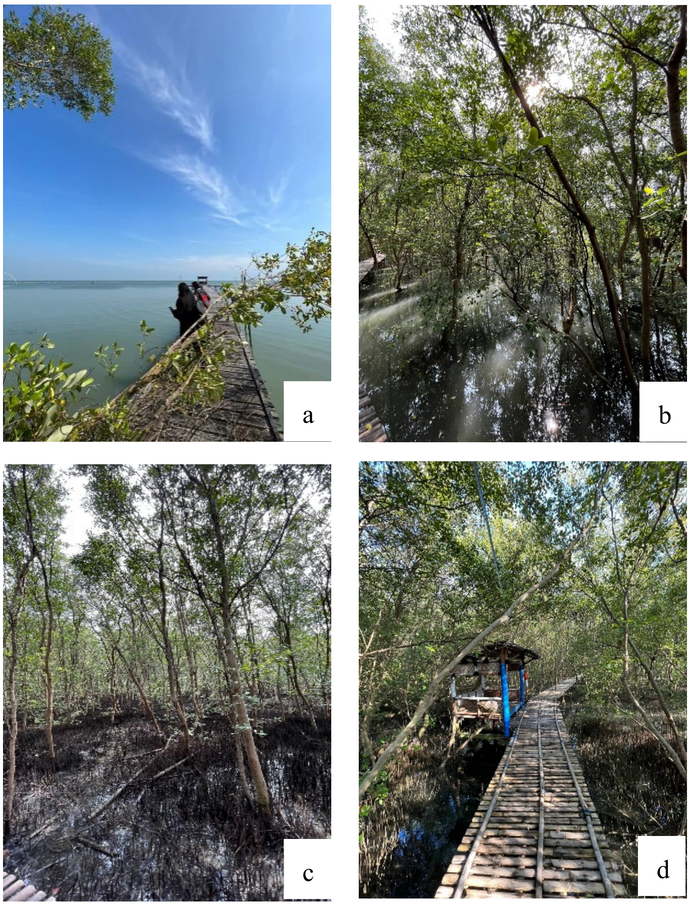


**Fig. 2.** Research locations condition on mangrove ecosystem of Bedono Village, Sayung, Demak, Cental Java (a: near Java Sea; b: middle of mangrove; c: middle of mangrove; d: Entrance area)

**Table 1.** Water quality classification based on the US-EPA rating system

| Score | Class | Character of Water Quality |
|---|---|---|
| 0 | A | Not polluted |
| -1 to -10 | B | Lightly polluted |
| -11 to -30 | C | Moderately polluted |
| ≥ -31 | D | Heavily polluted |

The determination of water quality status using the STORET method is carried out by collect data on water quality periodically to form a data set over time (time series) and compare the measurement data for each water parameter with the quality standard value according to the water class. If the measurement results meet the water quality standards (measurement results < quality standards), then a score of 0 is given. If the measurement results do not meet the water quality standards (measurement results > quality standards), then a score is given, as shown in Table 2. The negative sum of all parameters is calculated, and the quality status of the total score being obtained using the specified scoring system.

The Pollution Index value can be determined by selection the parameters and the concentration of standard parameters. If the parameter value is low, then the water quality will be good. Ci/Lij values are calculated for each parameter at each sampling location. If the parameter concentration value is low, the pollution level is high. PIj value is determined by:

**Table 2.** Assessment of water quality parameters (MoE No. 115/2003)

| Parameter | Score | Parameter | | |
|---|---|---|---|---|
| | | Physics | Chemistry | Biology |
| < 10 | Maximum | -1 | -2 | -3 |
| | Minimum | -1 | -2 | -3 |
| | Average | -3 | -6 | -9 |
| ≥ 10 | Maximum | -2 | -4 | -6 |
| | Minimum | -2 | -4 | -6 |
| | Average | -6 | -12 | -18 |

**Table 3.** Pollution category based on Pollution Index (PI)

| PI Score | Description |
|---|---|
| 0 ≤ PI ≤ 1 | Good condition |
| 1≤ PI ≤ 5 | Lightly polluted |
| 5 ≤ PI ≤ 10 | Moderately polluted |
| PI > 10 | Heavely polluted |

$$PIj = \sqrt{\frac{\left(\frac{Ci}{Lij}\right)^2 M + \left(\frac{Ci}{Lij}\right)^2 R}{2}}$$

where:
PIj: Pollution Index for designation (j)
Ci: Concentration of water quality parameters (i)
Lij: Concentration of water quality parameters stated in the quality standard for water use (j)
(Ci/Lij)M: maximum value Ci/Lij
(Ci/Lij)R: average value Ci/Lij

The determination of water class is carried out by comparing the concentrations of all water quality parameters listed in Government Regulation 22 of 2021 and then comparing with seawater quality standards (Appendix VIII) for ship harbor, marine tourism, and marine biota.

Data analysis used includes analysis of water quality based on physical and chemicals parameters compared to Table 3 as follows.

## RESULTS AND DISCUSSION

The water temperature of the mangrove ecosystem in Bedono Village during survey ranged between 28,6°C to 31,03°C; the lowest temperature was in B3 (Figure 3). Changes in water temperature may relate to the time of day, air circulation, water flow, tides, river depth (Muhaemi et al. 2015), microclimate, loss of riparian vegetation, and rain (Bhateria and Jain 2016).

The pH in the mangrove ecosystem Bedono Sayung, Demak was neutral, in the range of 6.5-7.5, with conductivity of 15.06-22.03 mS/sec (Figure 3). Water acidity was influenced by water temperature through seasonal distribution, day and night, human activities, agricultural, or sediment particles (Wu et al. 2020).

The lowest values for dissolved oxygen (DO) and Chemical Oxygen Demand (COD) were recorded at site B4 (Figure 3). Site B3 had the highest DO (8, 78 mg $L^{-1}$) and the lowest Biological Oxygen Demand (BOD) (30 mg $L^{-1}$), salinity, and total dissolved solids (TDS). The

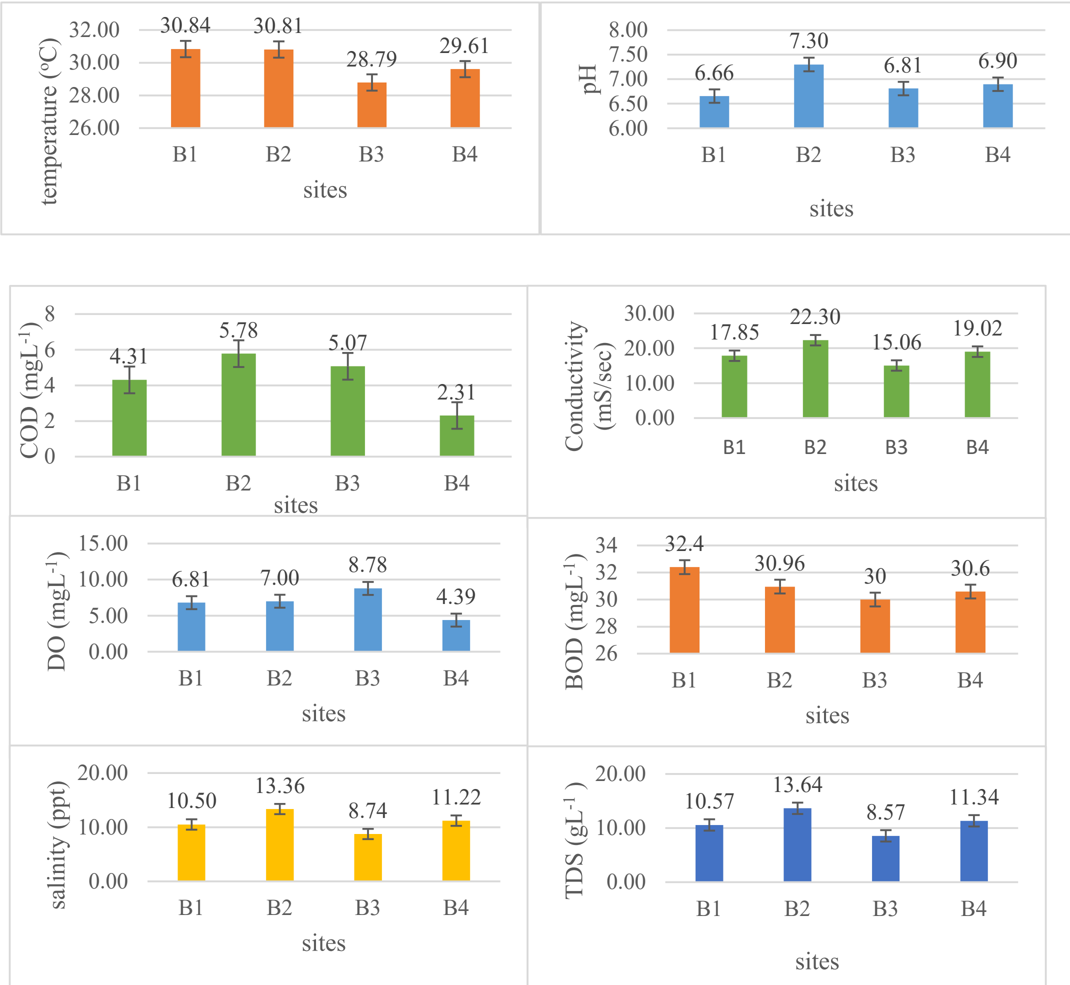


**Fig. 3.** Water quality at the mangrove ecosystem at Bedono, Sayung, Demak, Central Java

DO is related to the water temperature in that an increase in temperature results in lower the DO (Sinaga et al. 2016). A high BOD concentration indicated high organic content (Nuraini et al. 2019). A low DO concentration is usually attributable to the high COD and BOD concentration (Aldo et al. 2015).

Heavy metals of Cadmium (Cd) and Copper (Cu) in all sites are less than 0.01 mg $L^{-1}$, but lead (Pb) and chromium (Cr) at all research sites are exceeded the threshold for harbor (0.05 mg $L^{-1}$ Pb, 0 $mgL^{-1}$ Cr) , tourism (0.005 $mgL^{-1}$ Pb, 0.002 $mgL^{-1}$ Cr), and marine biota (0.008 $mgL^{-1}$Pb, 0.005 $mgL^{-1}$ Cr) (Figure 4).

The highest ammonia values were returned at site B4, whereas total nitrogen (TN) was highest at B1 (Figure 5). Ammonia was oxidized to nitrate. Usually the concentration of nitrate was higher than nitrite, as nitrite was unstable and tended to transition from ammonia to nitrate (Patty 2015). High $N_2O$ content was also found in China's mangrove ecosystems, assuming accumulation from greenhouse gases (Yang et al. 2018). Total N content contributes significantly to global warming. A relatively low temperature and a high humidity may result in high concentrations of ammonia (Yin et al. 2018). This may be elevated due to high river turbidity, low DO, but pH was neutral (Erisman 2021).

Rivers that pass through industrial, agricultural, and residential areas usually have high ammonia content (Putri et al. 2019). High ammonia will reduce dissolved oxygen levels, disrupting the

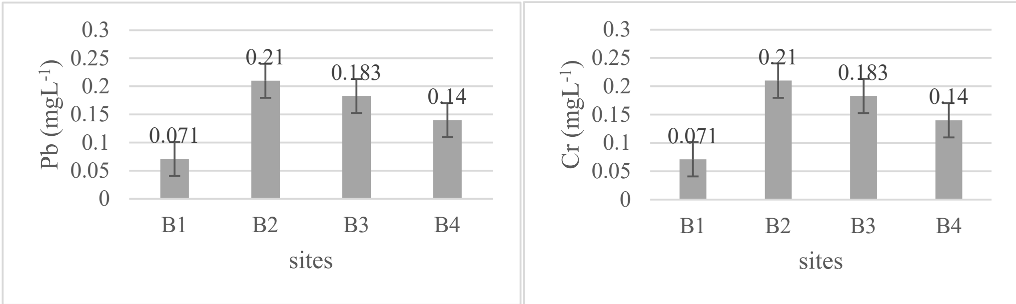


**Fig. 4.** Heavy metals at mangrove ecosystem Bedono, Sayung, Demak, Central Java

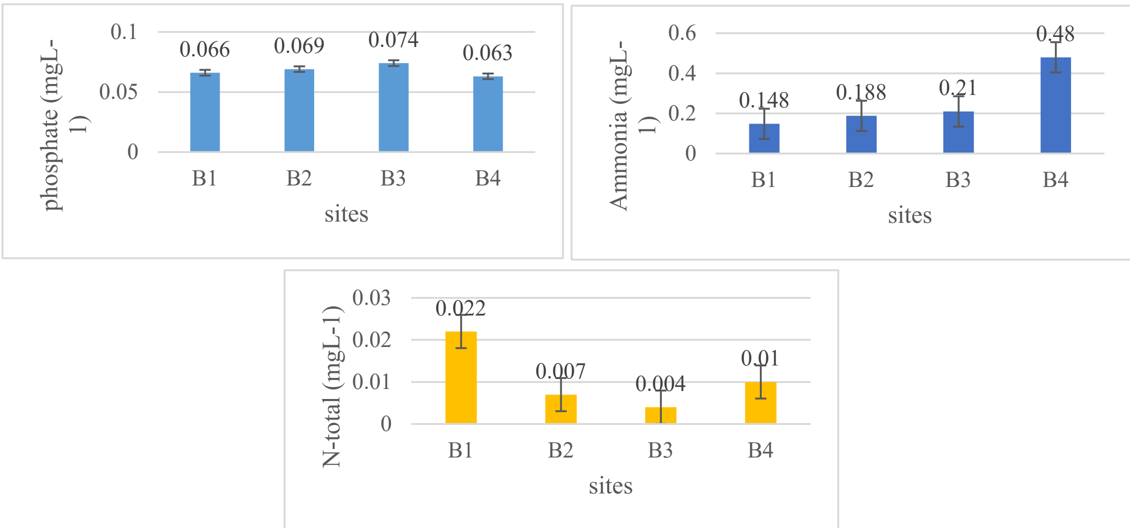


**Fig. 5.** Nutrients at mangrove ecosystem Bedono, Sayung, Demak, Central Java

physiological processes and metabolism of aquatic biota (Zhang et al. 2017). Fertilizer residues in the environment increase the concentration of phosphates in rivers. High organic content will increase water productivity and reduce dissolved oxygen (Bosman et al. 2021).

Calculations of the water quality state in the mangrove ecosystems followed the standards for marine waters for harbour, marine tourism, and marine biota as stated in Appendix VIII, of Government Regulation 22 of 2021 and then through comparison with seawater quality standards. Based on the results of the STORET index calculation, the values for harbour function was moderate (-16), marine tourism low (-80), and marine biota low (-90) (Figure 6). Based on the STORET method, the mangrove ecosystem in Bedono, Sayung, Demak for harbour is in the class C category, (moderately polluted waters), for marine tourism and marine biota it is in the class D category (heavily polluted waters).

The pollution index (PI) values returned from the Bedono mangrove ecosystem samples shows Sites B1 to B4 for harbor function are lightly polluted (Figure 7), whereas for marine tourism it is in a light-heavy polluted condition, and for marine biota is in a moderate-severe polluted condition. The Pollution Index has a different concept from the STORET. IP is determined for an allotment of a drainage system; then, it can be developed for several designations for all parts of a water body or part of a water body. The pollution index is a method used to determine the amount of pollution in waters in the form of numbers to make it easier to know the levels of

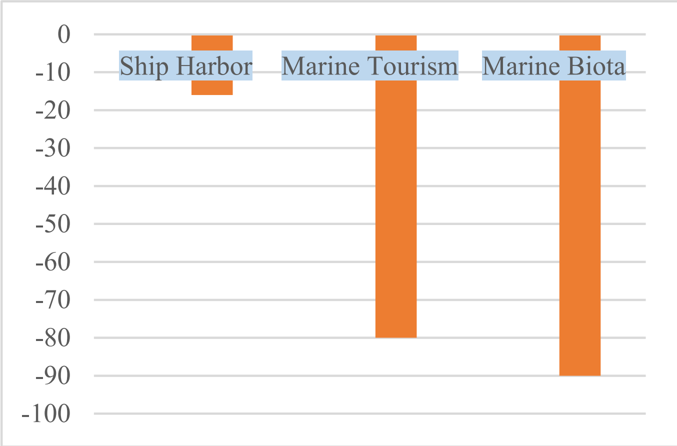


**Fig. 6.** Water quality of mangrove ecosystem at Bedono, Sayung, Demak based on STORET method

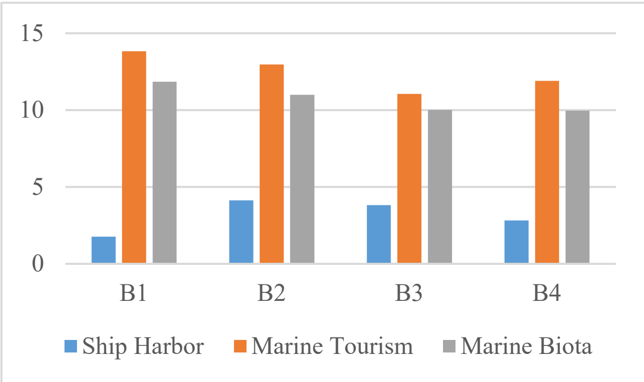


**Fig. 7.** Pollution Index at mangrove ecosysytem in Bedono, Sayung, Demak

pollution (Ruspita and Atika 2022)

The pollution index is useful in providing the results of an initial assessment of water quality status. Estimating the water pollution index provides a single value that synthesizes the data of many parameters (Poonam et al. 2013). This initial rapid water quality assessment should be followed by the regular monitoring necessary to provide a more comprehensive assessment of water quality for ecosystem health (Alves et al. 2014).

The STORET method, based on subjectivity weights and parameter scores, is considered a robust approach in the USA, where the index was developed. In the IP calculation, there is no sub-index score scheme or subjective score per parameter; the most significant parameter is calculated based on the largest concentration ratio to its quality standard. The IP method is calculated by considering the concentration ratio of a parameter with its maximum quality standard (Ci/Lij) and the average ratio of several water quality parameters only from one or a single water sample taken during collection activities (Harahap et al. 2020).

The analysis results using the STORET and PI methods tend to have the same results for the site: moderate-to-severe contamination. Parameters that exceed the standard thresholds for seawater quality include DO, BOD, phosphate, ammonia, Cr, and Pb. In general, river water quality is influenced by the water flow rate from upstream to downstream and human activities in the catchment area.

Communities in Demak Regency generally use inorganic agricultural fertilizers subsidized by the Indonesian government. Agricultural, household, and industrial waste, and the impact of boat fuel, affect the levels of pollution experienced in the Bedono mangrove ecosystem. Heavy metals, primarily present in industrial wastewater, pose a significant risk to the mangrove ecosystem as representative pollutants (Algül and Beyhan 2020; Sun et al. 2022). Contamination is a major problem for communities all over the world. Furthermore, coastal regions are more likely to be polluted because they are hotspots for increased urbanization and industrialization. Because of its proximity to anthropogenic inputs, marine life is more vulnerable.

The high concentrations of nitrate and phosphate tend to accumulate in water on account of human activities. Forms of N and P are generally absorbed by plants as macronutrients and can contribute to soil fertility (Wang et al. 2019). Accumulation of heavy metals Cr and Pb were observed in the East Flood Canal (Sari and Soeprobowati 2021), where greatest yields were found in the downstream areas. The concentration of heavy metals in the river increases along with the volume of discharged wastewater (Luthansa et al. 2021).

The ecological balance of the coastal waters environment will be maintained if mangroves are maintained because they function as biofilters, binding agents, and pollution traps. While mangroves have a high tolerance for heavy metals (Mac Farlane and Burchett 2001; Gunarto 2004) they are vulnerable to heavy metal waste, as are the organisms that inhabit mangrove ecosystems. This is because heavy metals are elements that cannot be created or destroyed (non-degradable) naturally, so they persist in receiving waters (Nana and Andin 2014).

Mangrove communities often receive pollutants such as heavy metals from industrial, household, and agricultural waste. Heavy metals dissolved in water will move into the sediment if they bind to free organic matter or organic material that coats the surface of the sediment. Organic matter in sediments and metal absorption capacity is closely related to particle size and surface area of absorption, so the concentrations of metals in sediments are usually influenced by the particle size in the sediment (Edyson et al. 2017).

## CONCLUSIONS

Parameters that were found to exceed the threshold for seawater quality standards included DO (<5), BOD (<10 for marine tourism and <20 for marine life), phosphate (<0.015 mg/L for marine tourism, and marine biota), ammonia for all categories, Cr, and Pb.

The water quality in the Bedono Demak mangroves ecosystem is classified as moderately - heavily polluted based on the Storage and Retrieval (STORET) and Pollution Index (PI) methods. Sustained high pollution levels poses a risk to mangrove forests and the biota that live within them.

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## CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

## LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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