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Original Research Article

Characterization of Water Quality and Evaluation of Pollution Levels Around Final Disposal Sites (TPA)

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Abstract

This study evaluates water quality and pollution levels surrounding the Degayu Landfill, Pekalongan City, focusing on nutrient characteristics. Landfills generate leachate containing organic and inorganic compounds that can contaminate nearby water bodies if mismanaged. We conducted a survey by sampling water at several locations around the landfill to analyze nutrient-related parameters, specifically ammonia, nitrite, and phosphate. The data were analyzed descriptively, compared with applicable water quality standards, and assessed using the pollution index method to determine overall water quality status. Furthermore, Spearman correlation analysis identified relationships among these parameters. Results indicate varying nutrient concentrations, with increases at specific locations. The pollution index values suggest a decline in water quality at several observation points relative to established standards. Notably, correlation analysis revealed a strong relationship between ammonia and nitrite, highlighting their role in nitrogen transformation within the aquatic environment. In conclusion, water quality around the Degayu Landfill is demonstrably influenced by nutrient concentration variations, indicating a potential impact on the ecological balance of the surrounding aquatic ecosystem.

Keywords: Degayu landfill; leachate; nutrients; pollution index; water quality

1. Introduction

Leachate is liquid that percolates through piles of waste, carrying dissolved or suspended materials, primarily resulting from the decomposition of landfill waste (Harfadli et al., 2019). Leachate poses a risk of environmental contamination because it contains toxic compounds and pathogenic microorganisms. Global studies indicate that groundwater and surface water near landfills are the most vulnerable media, more so than soil. Their contents often include high NH_4-N, elevated COD/BOD, chlorides, sulfates, and heavy metals such as Cd, Cr, Pb, Ni, and Mn, which are toxic and carcinogenic (Shijun et al., 2022). Therefore, leachate quality must be assessed and treated before being discharged into water bodies. To mitigate leachate-related problems, treatment efforts must be implemented directly at landfill sites.

Several previous studies have shown that the closer the distance to the leachate source (TPA), the higher the risk of groundwater contamination, particularly by heavy metals and other water quality parameters, ultimately threatening human health and aquatic ecosystems. For example, at the Alak landfill (Kupang), well water quality remained safe at distances of 800–1,200 m from the landfill, but at 400 m the water quality became concerning, highlighting the need for improved landfill management (Finmeta et al., 2020).

Degayu landfill is one of the final disposal sites in Pekalongan City, covering an area of 5.8 hectares and located 6 km from the city center. Situated in Degayu Village, North Pekalongan District, the site lies in a coastal area with an elevation of approximately ±6 meters above sea level. The landfill is only 0.1 km from a water body, making it highly vulnerable to tidal flooding. Flooding at Degayu landfill increases leachate production, while rainwater infiltration further contributes to leachate generation. This leachate then seeps into wells along with rainwater, causing groundwater and surface water contamination. Leachate management at Degayu landfill remains suboptimal, compounded by the integration of the leachate treatment plant, with the fecal sludge treatment plant, which allows sewage to enter the leachate treatment system.

Although numerous studies have examined the impact of leachate on water quality around landfills, research focusing on landfill sites located in coastal areas remains relatively limited. Furthermore, evaluations of pollution levels using the pollution index approach in waters surrounding Degayu landfill have not been widely reported. Therefore, research is needed to provide an overview of water quality conditions and pollution levels in this area.

This study aims to evaluate water quality at several water bodies around Degayu landfill and determine pollution levels using the pollution index method. The findings are expected to provide preliminary information on the environmental condition of waters near the landfill and serve as a basis for future management and monitoring efforts.

2. Methods

2.1. Time and Location

The research was conducted at Degayu landfill (TPA Degayu), Pekalongan City, on January 3, 2024. Leachate samples were collected from four points. The sampling points are shown in Figure 1.

Figure 1. Sampling locations of leachate and fishpond water
Point KL (6°52’04.7”S 109°42’20.9”E) represents the Degayu landfill leachate pond, Points KT1 (6°52’05.1”S 109°42’20.0”E), KT2 (6°52’05.7”S 109°42’20.6”E), and KT3 (6°52’02.8”S 109°42’27.7”E) correspond to the front, side, and rear fishponds adjacent to Degayu landfill.

In addition to the coordinates of each sampling point, the distances from the leachate pond are presented in Table 1.

Table 1. Distance of sampling points from the leachate pond

Sampling Point	Unit	Distance from TPA
KL	meter	0
KT1	meter	30
KT2	meter	35
KT3	meter	20

From the sampling distance data, KT3 represents the closest point to the leachate pond. The parameters examined for leachate water quality included pH, COD, BOD, TSS, total nitrogen, and cadmium (Cd). For fishpond water quality, the parameters analyzed were salinity, temperature, pH, dissolved oxygen, alkalinity, nitrite, ammonia, organic matter, and phosphate. Measurements were also conducted on clean water used for hygiene and sanitation, obtained from local wells around Degayu landfill, Pekalongan City. Samples were collected using 1-liter HDPE bottles, labeled, and stored in a cooler box. Laboratory analyses were carried out at the Environmental Engineering Laboratory, Diponegoro University.

2.2 Data Analysis

Leachate and fishpond water quality data were assessed to determine whether the concentrations of substances met established quality standards. The standards for leachate refer to the provisions in the Minister of Environment and Forestry Regulation No. 59 of 2016 on Leachate Quality Standards for Landfill Operations. Fishpond water quality was compared with the standards outlined in the Minister of Marine Affairs and Fisheries Decree No. Kep. 28/MEN/2004 on Aquaculture Water Quality.

To examine relationships among water quality parameters, Spearman's correlation test was applied. This method was chosen because it does not require the assumption of normal distribution and is suitable for limited sample sizes. The Spearman correlation coefficient was used to indicate the strength of relationships among the observed water quality parameters.

3. Results and Discussion

Parameter	Unit	Sampling Point				Quality Standard
		KL	KT1	KT2	KT3	
BOD	mg/L	480	-	-	-	300*
COD	mg/L	1533.3	-	-	-	150*
TSS	mg/L	68	-	-	-	100*
N-Total	mg/L	316.6	-	-	-	60*
Cd	mg/L	0.062	-	-	-	0.1*
pH		7.56	7.75	7.37	7.18	6-9* 7.5 – 8.5**
Salinity	ppt	-	11.2	30.1	28.8	15 – 25**
Temperature	°C	-	41	41	39	28.5 – 31.5**
Dissolved Oxygen	mg/L	-	9.8	8.5	3.3	3 – 7.5**
Alkalinity	mg/L	-	215	235	225	120 – 160**
Nitrite	mg/L	-	0.019	0.945	1.091	0.01 – 0.05**
Ammonia	mg/L	-	0.521	2.375	3.559	0.05 – 0.1**
Organic Matter	mg/L	-	34.13	24.02	67.62	<55**
Phosphate	mg/L	-	0.028	0.113	0.246	0.1 – 0.25**

Sources:
* =Minister of Environment and Forestry Regulation No. 59 of 2016 on Leachate Quality Standards for Landfill Operations.
** =Minister of Marine Affairs and Fisheries Decree No. Kep. 28/MEN/2004 on Aquaculture Water Quality.

3.1 Characteristics of Water Quality Around Degayu Landfill

The measurement results at the observation points revealed variations in the physical and chemical parameters of waters surrounding the study site. Water temperature values were relatively uniform across sampling points, indicating that thermal conditions remained within the typical range for coastal fishpond environments.

pH values at the sampling points showed neutral to slightly alkaline conditions, suggesting that the waters still possessed adequate buffering capacity to maintain chemical stability. Dissolved oxygen (DO) levels varied among locations, likely influenced by biological activity and the degree of organic matter decomposition. Beyond these physical parameters, several chemical indicators—particularly nutrients—exhibited marked differences across sampling points. Ammonia and nitrite concentrations were relatively higher at certain sites, pointing to organic matter accumulation and decomposition processes. Elevated nitrogen compounds often signal microbial activity in breaking down organic inputs.

Consistent with previous studies on water quality near landfills, the average condition of waters around Degayu landfill was poor due to leachate contamination. Many studies have reported increases in BOD, COD, nitrate, ammonia, Fe, Mn, and occasionally heavy metals, as well as pH values outside quality standards. Turbidity, dark coloration, and coliform/E. coli contamination are also commonly observed (Agustina et al., 2021).

3.2 Characteristics of Aquatic Nutrients

Nutrient characteristics at the study site were analyzed based on concentrations of key parameters in the nitrogen and phosphorus cycles—ammonia, nitrite, and phosphate. These parameters serve as important indicators of water fertility and potential pollution from anthropogenic activities.

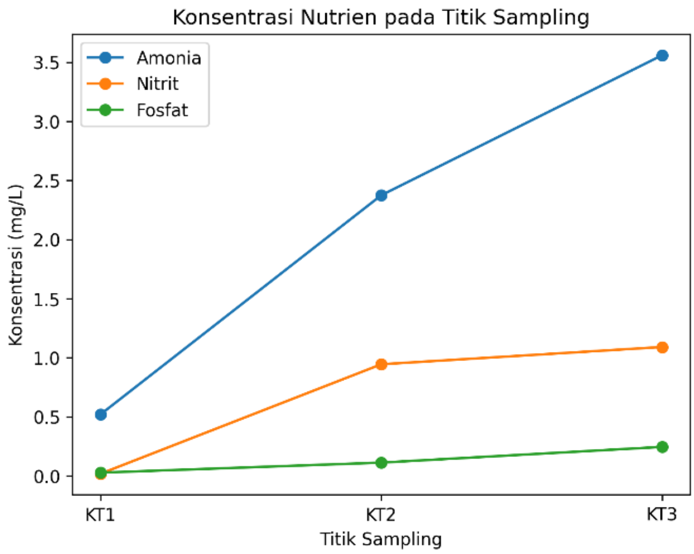

Figure 2. Nutrient concentrations at sampling points

Measurements showed that ammonia concentrations tended to increase from KT1 to KT3. KT1 had relatively lower ammonia levels, while KT2 and KT3 exhibited significant increases, suggesting organic matter accumulation and decomposition producing nitrogen compounds. Elevated ammonia is often linked to microbial breakdown of organic matter.

Nitrite concentrations also rose from KT1 to KT3. As an intermediate compound in nitrification, nitrite reflects the oxidation of ammonia by nitrifying bacteria. Its increase indicates that nitrogen transformation processes were actively occurring in the aquatic system. Phosphate concentrations were lower compared to nitrogen parameters but still showed an upward trend from KT1 to KT3. Phosphate is a key nutrient for aquatic organisms, particularly phytoplankton and algae. Rising phosphate levels suggest external nutrient inputs that may enhance water fertility.

These findings align with earlier studies reporting that waters near landfills tend to be nitrogen-rich (especially ammonium and total N) and often contain elevated phosphorus compared to natural conditions (P et al., 2016). High N and P inputs from leachate increase eutrophication potential when discharged into surface waters (Kapelewska et al., 2019). Ammonium dominance in leachate is frequently followed by nitrification, raising nitrate levels in groundwater and downstream rivers (Przydatek, 2019).

3.3 Evaluation of Pollution Status

The analysis confirmed the presence of pollutants in leachate affecting water quality around Degayu landfill. Several parameters exceeded established quality standards. To evaluate the extent of pollution caused by leachate, the Pollution Index (PI) was calculated for river and well water quality using the following formula:

$$IP = \frac{\sqrt{\left(\frac{Ci}{Lij}\right)^2_M + \left(\frac{Ci}{Lij}\right)^2_R}}{2}$$

Pollution Index (PI) Explanation :
IP (Pollution Index) = indicator of pollution status
C = concentration of the parameter
Lij = quality standard value of the parameter
M = maximum value
R = average value

Water quality status is determined by comparing the maximum and average ratios of parameter concentrations against their respective quality standards. The classification of water quality based on the Pollution Index (PI) is as follows:

Score $0 \leq Pij \leq 1.0$ = Good
Score $1.0 < Pij \leq 5.0$ = Slightly Polluted
Score $5.0 < Pij \leq 10$ = Moderately Polluted
Score $Pij > 10$ = Heavily Polluted

Fishpond Sample 1 (KT1)

$\left(\frac{Ci}{Lij}\right)_M$ = 17.84

$\left(\frac{Ci}{Lij}\right)_R$ = 3.96

IP $= \frac{\sqrt{\left(\frac{Ci}{Lij}\right)^2_M + \left(\frac{Ci}{Lij}\right)^2_R}}{2}$

$= \frac{\sqrt{(17.84)^2 + (3.96)^2}}{2}$

= 9.137

Fishpond Sample 2 (KT2)

$\left(\frac{Ci}{Lij}\right)_M$ = 92

$\left(\frac{Ci}{Lij}\right)_R$ = 17.31

$$IP = \frac{\sqrt{(\frac{Ci}{Lij})^2{}_M + (\frac{Ci}{Lij})^2{}_R}}{2}$$
$$= \frac{\sqrt{(92)^2+(17.31)^2}}{2}$$
$$= 46.8$$

Fishpond Sample 3 (KT3)

$$(\frac{Ci}{Lij})_M = 139.36$$
$$(\frac{Ci}{Lij})_R = 23.26$$
$$IP = \frac{\sqrt{(\frac{Ci}{Lij})^2{}_M + (\frac{Ci}{Lij})^2{}_R}}{2}$$
$$= \frac{\sqrt{(139.36)^2+(23.26)^2}}{2}$$
$$= 70.65$$

Based on the calculated Pollution Index (PI) values at each observation point, variations in pollution levels were observed across the study site. The PI values for each sampling location are illustrated in Figure 3.

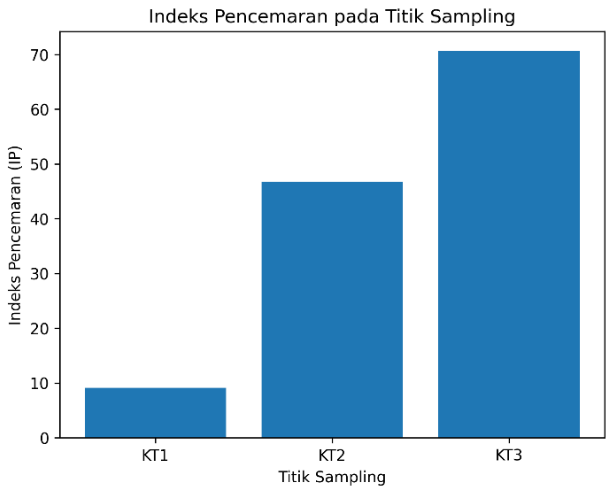

Figure 3. Pollution index at sampling points

Overall, the obtained PI values indicate that water quality at several observation points has declined compared to the established standards. Relatively high PI scores at certain sites suggest environmental pressures affecting aquatic conditions around the landfill. The elevated PI values are likely influenced by several water quality parameters with relatively high concentrations, particularly nutrient parameters such as ammonia and nitrite. Increased nutrient concentrations are often associated with organic matter inputs undergoing decomposition, producing dissolved nitrogen compounds in the water.

It is evident that KT3 recorded the highest Pollution Index, which can be attributed to its proximity to the landfill. The closer distance resulted in higher pollutant concentrations at KT3. This finding is consistent with previous research, which reported that water quality improves as the distance from the landfill increases (Finmeta et al., 2020).

3.4 Analysis of Relationships Among Water Quality Parameters

The relationships among water quality parameters were analyzed using Spearman's correlation test to identify linkages among the observed nutrient parameters at the study site. Spearman's test was chosen because it does not require normally distributed data and is suitable for relatively small sample sizes. The Spearman correlation coefficient (r) was used to indicate the strength and direction of relationships among parameters, while the significance value determined whether the relationships were statistically meaningful.

Table 2. Spearman correlation analysis results

Parameter	Ammonia	Nitrite	DO
Ammonia	1	1	-1
Nitrit	1	1	-1
DO	-1	-1	1

Notes:

- Positive values = direct relationship
- Negative values = inverse relationship

The correlation analysis revealed a strong relationship among several nutrient parameters, particularly between ammonia and nitrite. The positive correlation between these two parameters indicates that increases in ammonia concentration tend to be accompanied by increases in nitrite concentration. This pattern can be explained by the nitrification process, in which ammonia is oxidized to nitrite by nitrifying bacteria in aquatic environments. This relationship is clearly illustrated in the scatter plot shown in Figure 4.

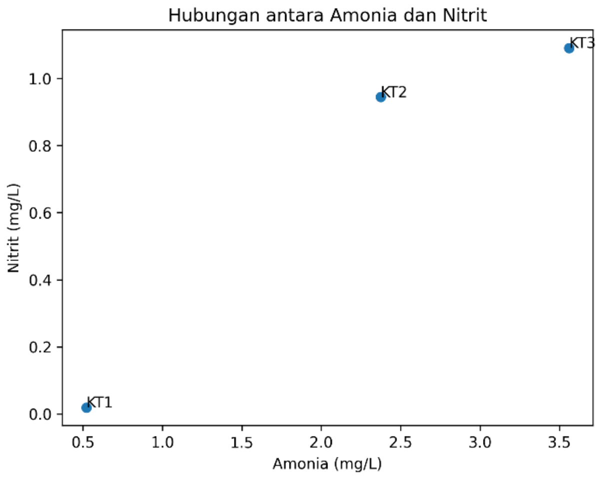

Figure 4. Scatter plot of nutrient correlations

Additionally, the relationships among nutrient parameters are influenced by the decomposition of organic matter in the water. Decomposed organic matter produces nitrogen compounds in the form of ammonia, which are subsequently transformed into nitrite and nitrate through microbial activity. Thus, the presence of nutrients in aquatic systems often reflects interconnected processes within the nitrogen cycle. Leachate from landfills, which is typically rich in ammonia, tends to inhibit nitrite-oxidizing bacteria (NOB), resulting in nitrite accumulation (partial nitritation) (Kim et al., 2006).

4. Conclusion

Based on the findings, water quality around Degayu landfill (TPA Degayu) exhibited variations in nutrient concentrations across sampling points. Ammonia, nitrite, and phosphate showed increasing trends at several locations, indicating the influence of organic matter inputs on aquatic conditions. The evaluation using the Pollution Index (PI) demonstrated that water quality at several points had declined, with some sites classified as heavily polluted. Spearman's correlation analysis further confirmed strong relationships among nutrient parameters, particularly between ammonia and nitrite, consistent with ongoing nitrification processes in the aquatic environment.

CRediT Author Statement

Muhammad Bintang Wahyuarta: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review and editing, and Final approval of the version submitted. **Ariesta Sulistyo Asih:** Supervision and Review. **Ika Bagus Priyambada:** Supervision and Review.

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