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Assessment of Leachate Treatment Efficiency and Its Impact on Surface Water Quality at the Blang Bintang Landfill, Aceh Besar

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ABSTRACT

This study aims to evaluate the effectiveness of the leachate treatment plant at the Blang Bintang Regional landfill and analyze its impact on the water quality of the Krueng Uteun Siblah River. The method used is a comparative analysis of leachate quality monitoring data (influent and effluent) from the landfill from 2021 to 2025. The results showed that the treatment plant successfully reduced the concentration of pollutants in leachate, with an average efficiency percentage for the parameters of Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and Total Suspended Solids (TSS) Nitrate, NH_3, Cd, Fe were 23.87%, 64.15%, 50.53%, 35.26%, 62.19%, 71.05%, and 40.18%, respectively. However, effluent values for COD and BOD parameters still exceed the established quality standards. Further analysis of the Krueng Uteun Siblah River revealed a significant decline in water quality immediately after the leachate outfall point, marked by a spike in BOD (27.4-30 mg/L), COD (51.17-62 mg/L), and iron concentration (3.65-4.21 mg/L) that exceeded quality standards, as well as a drastic decrease in Dissolved Oxygen (DO) levels to 3.5 mg/L improving the performance of leachate treatment facilities and implementing stricter management strategies are absolutely necessary to protect the aquatic ecosystem around the landfill.

1. INTRODUCTION

Blang Bintang Landfill is one of the biggest and the most up-to-date final waste processing sites in Aceh Province. It is located in Data Makmur Village, Blang Bintang, Aceh Besar. This landfill also known as the Aceh Regional Integrated Final Processing Landfill Site (UPTD TePAT SaReA), which was built to support the regional waste management system with a sanitary landfill approach.

Geographically, this landfill located at coordinates 95°27'50“ – 95°28'57” East Longitude and 5°30'36“ – 5°31'42” North Latitude. The construction of this facility started in 2010. The landfill’s service area covers two regions, namely Aceh Besar Regency (since 2013) and Banda Aceh City (since 2018). The total area of the landfill is 206 hectares, with currently 52 hectares already in use for operations. The Blang Bintang Landfill is equipped with facilities such as leachate storage ponds and an environmental management system. As a regional landfill, this site not only functions as a final disposal site but also forms part of a waste management education program based on the 4R principles (Reduce, Reuse, Recycle, Replace). Despite having fairly good infrastructure, leachate management remains its main challenge.

The Wastewater Treatment Plant (WWTP) also known as IPAL at the regional landfill is a system designed to treat leachate generated from waste piles before it is discharged into the environment. This facility consists of a series of treatment tank, Anaerobic Baffled Reactor (ABR), aeration tank, maturation tank, and chlorination tank to reduce the concentration of physical, chemical, and biological pollutants in leachate so that it is safe when discharged into rives, in order to minimize the impact of pollution on the surrounding environment (Dari & Suhartini, 2024; Lestari, 2020). IPAL plays a key role in treating leachate from landfills. The IPAL treatment process is designed to reduce the concentration of pollutants such as organic matter, ammonia, and dissolved solids before they are discharged into the environment. The effectiveness of IPAL is crucial in controlling the impact of leachate on surface water quality (Omofunmi *et al*., 2020; Gunarathne *et al*., 2024).

Leachate is a liquid formed from the infiltration of rainwater or soil moisture through waste piles in landfills, carrying with it dissolved organic, inorganic, and heavy metal materials. Leachate has the potential to contaminate surface water and surrounding soil, especially if the landfill is not equipped with an adequate treatment system. This liquid contains various pollutants such as organic matter, ammonia, heavy metals, and emerging contaminants such as PFAS and microplastics (Gyabaah *et al*., 2024; Yuan *et al*., 2022; Chen *et al*., 2024; Bo Hu, 2024). This liquid is formed when rainwater seeps through waste piles containing high concentrations of organic pollutants, ammonia nitrogen, heavy metals, and various other hazardous compounds. Its complex and toxic composition poses a serious threat to surface water quality if not treated before being discharged into the environment and threatens aquatic ecosystems (Angrianto *et al*., 2021; Emalya *et al*., 2024; Prisilla, 2024).

River water is a vital resource for life, but its quality is highly vulnerable to the impacts of human activities, including waste disposal. Polluted rivers not only lose their clarity but also their ability to support aquatic life and meet environmental quality standards. This condition can be influenced by various factors, including the entry of pollutants that alter the natural composition of water and potentially reduce its function for the environment (Nurbaya & Sari, 2023; Mardizal *et al*., 2024; Sahabuddin, 2015; Zaman *et al*., 2023). River water quality is highly susceptible to contamination due to leachate percolation from landfills. Leachate contains high concentrations of organic compounds, heavy metals, and other toxic substances. This pollution threatens public health and aquatic ecosystems, making effective leachate management essential for maintaining river water quality (Dwiratna *et al*., 2024).

Waste management systems using open dumping methods at various landfills in Indonesia have the potential to cause serious environmental impacts. Leachate containing heavy metals and organic pollutants can contaminate surrounding surface water bodies (Meyrita, 2023). Conventional treatment processes are often ineffective, requiring technological improvements such as partial nitrification-denitrification (PND) to reduce pollutant loads and carbon emissions (Sheng *et al*., 2024).

The novelty of this study lies in its examination of the Krueng Uteun Siblah River, which has been limited in scientific research, as well as in its integrated approach linking wastewater treatment plant performance, treatment efficiency, and pollution index as indicators of surface water quality. In addition, this study analyzes WWTP performance trends over a five-year period and evaluates WWTP performance efficiency and compliance with environmental standards, which are rarely reported in wastewater management studies in Indonesia.

Based on the results of monitoring the quality of leachate from the Blang Bintang Regional Landfill and the Krueng Uteun Siblah River in 2025, this study was conducted to analyze the effectiveness of the leachate treatment process and assess its impact on surface water quality. This research aims to evaluate the efficiency of leachate treatment based on the parameters of BOD, COD, TSS, NH_3N, Nitrate, Cd, Fe, and Hg, asssess the level of effluent compliance with the quality standards set in regulation of the Minister of Environment and Forestry (Menteri LHK, 2016, and analyze the indications of the impact of effluent discharge on river water quality in the downstream section. The results of the analysis show that although the treatment plant successfully reduced the concentration of major pollutant parameters such as COD, BOD, and TSS in leachate, several parameters in the effluent discharged into water bodies still exceeded the applicable quality standards. Data analysis of the water quality of the Krueng Uteun Siblah River shows a significant decline in quality in the segment after the leachate outfall point, which is marked by an increase in BOD, COD, and iron exceeding quality standards, as well as a drastic decrease in DO levels. These findings confirm that the discharge of leachate effluent that does not meet standards has the potential to negatively impact river water quality, necessitating a comprehensive evaluation of the effectiveness of the treatment system and the strengthening of environmental management strategies in the Blang Bintang Regional Landfill area.

2. METHOD

2.1. Research Area Description

This study used a descriptive quantitative approach by collecting leachate and river water samples at several observation locations. Leachate samples were taken at the influent and effluent points, while river water samplaes were taken at the upstream, outfall, BPA, and downstream locations. Sampling was carried out twice, during the dry season (July) and the rainy season (September), at each observation location.

The samples obtained were then analyzed in the laboratory according to the established water quality parameters. The leachate parameters refer to regulation of the Minister of Environment and Forestry (Menteri LHK, 2016b, while the river water parameters refer to Government Regulation of the Republic of Indonesia (Presiden RI, 2021).

Testing was conducted in situ for pH, DO, and temperature parameters, followed by laboratory analysis at the Aceh DLHK BPPPL UPTD in accordance with applicable standard procedures. The test resuluts were analyzed descriptively and quantitatively to evaluate the efficiency of the treatment, compare water quality conditions before and after effluent discharge, and calculate the pollution level.

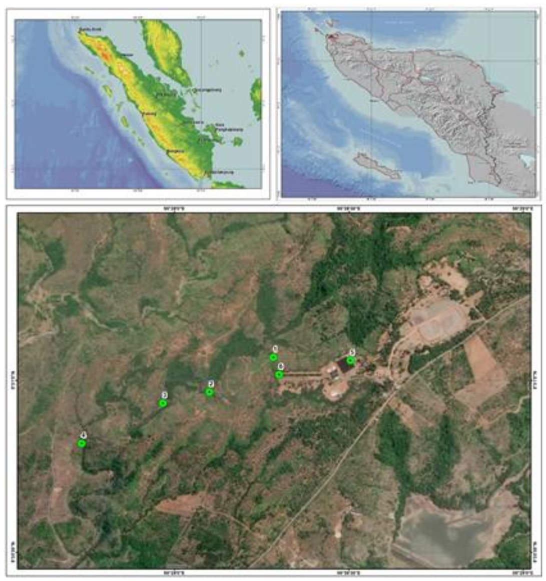


Figure 1. Research area

The map showed in Figured 1. Serves as a critical spatial basis for analysing distribution patterns and the level of environmental impact caused by marking the location codes of monitoring points to represent strategic locations along the Krueng Uteun Siblah River and the Blang Bintang Regional Landfill facilities. Each point is designed to monitor the distribution of impacts from leachate treatment, covering the upstream area, outfall, Krueng Uteun Siblah BPA, downstream, influent, and effluent at the Blang Bintang Regional Landfill to assess changes in surface water quality in relation to distance from potential sources of pollution.

2.2. Equipment and Materials

The Sampling process of leachate and water from the Krueng Uteun Siblah River was carried out using special materials and equipment. The materials used consisted of leachate and river water samples, sample blanks, ice boxes, and preservatives to maintain sample stability. Meanwhile, the equipment for sampling and measuring in-situ parameters includes a water sampler, polyethylene bottles, and Winkler bottles. Water quality measurements are carried out using a pH meter, DO meter, and mercury thermometer, all of which have undergone internal calibration. Other supporting equipment includes a GPS for location determination and a cool box for sample storage.

2.3. Sampling Method

The sampling method of leachate and river water is carried out with reference to SNI 8990:2021 (BSN, 2021) about Methods for Sampling Wastewater for Physical and Chemical Testing. The grab sampling method were used in this research, where samples are taken once at each location during two periods, namely the dry season and the rainy season. Each monitoring period is carried out in three stages, namely the initial preparation stage by collecting secondary data on the performance of the Wastewater Treatment Plant (WWTP) system and previous test results from the Regional Waste Management Center of the Aceh Environment and Forestry Agency, field surveys, and equipment preparation. The second stage involves collecting leachate and river water samples and measuring in-situ parameters. Parameters analysis was conducted in UPTD BPPPL DLHK Aceh using methods appropriate to the characteristics of each parameter. Dissolved oxygen (DO) analysis was performed using the Winkler method with titration device and Winkler-type BOD bottles. Gravimetric analysis was performed using a Sartorius analytical balance with an accuracy of 0.1 mg, a Memmert oven at 105 °C, and a Wetch vacuum pump. Spectrophotometer parameter analysis was performed using Shimadzu UV-Vis Spectrophotometer Type UV-2700. Meanwhile, a heavy metal analysis was performed using a Shimadzu Atomic Absorption Spectrophotometer (AAS) with a Graphite Furnace system.

Sampling was carried out using grab sampling at the inlet and outlet of the Leachate Treatment Plant (LTP), on the river 100 meters from the outlet, and in resident's wells at varying distances from the landfill. The samples were then analysed in the laboratory, and the test results were analyzed by comparing the parameters with the applicable water quality standards and calculating the IPL treatment efficiency (Dari & Suhartini, 2024).

2.4. Wastewater Treatment Plant Performance Efficiency

The efficiency of the wastewater treatment plant at the Blang Bintang Regional Landfill is measured by comparing the concentration of pollutants at the influent and effluent locations. Key parameters such as COD, BOD, TSS, and ammonia are analysed by calculating the percentage of removal for each parameter. The results are then compared with the applicable effluent quality standards. Efficiency was determined by measuring the concentration of contaminants at the inlet and outlet sampling points at the IPAL.

2.4.1. Laboratory Analysis

Organic compound analysis was performed using the solid phase extraction (SPE) method followed by ultra-performance liquid chromatography-mass spectrometry (UPLC-MS/MS) (Bracamontes-Ruelas *et al*., 2025). Conventional water quality parameters, including Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD), were analysed using standard methods applicable in the laboratory. All testing was conducted in an accredited laboratory in accordance with standard operating procedures.

2.4.2. Data Analysis

The removal efficiency is calculated by comparing the concentration of pollutant parameters at the inlet and outlet of leachate using the following equation:

$$\text{Efficiency (\%)} = \frac{(C_{in} - C_{out})}{C_{in}} \times 100\% \quad (1)$$

where C_{in} and C_{out} is respectively concentration parameters at the inlet and outlet of IPAL (mg/L).

The efficiency calculation results were then classified based on the percentage of removal to assess the performance level of the WWTP. The parameter concentration values at the outlet were then compared with the applicable environmental quality standards (Dari & Suhartini, 2024; Vidal *et al*., 2023).

Laboratory test data were analysed descriptively to evaluate compliance with applicable environmental quality standards. To asess the performance of the Wastewater Treatment Plant (WWTP), pollutant load removal efficiency was calculated using the formula proposed by (Metcalf & Eddy, 1991). Based on the percentage value obtained (X), performance efficiency is classified into five categories according to the criteria proposed by Metcalf & Eddy (1991), as follows: Very Efficient: X > 80%; Efficient: 60% < X ≤ 80%; Quite Efficient: 40% < X ≤ 60%; Less Efficient: 20% < X ≤ 40%; Not Efficient: X ≤ 20%.

Analysis of river water pollution levels using the Pollution Index method with the following formula:

$$PI_j = \sqrt{\frac{(C_i/L_{ij})_M^2 + (C_i/L_{ij})_R^2}{2}} \quad (3)$$

where C_i is concentration parameter value, L_{ij} is water quality value, PI_j is pollutant index, M is maximum value, and R is average value.

According to the Decree of the Minister of the Environment (MNLH, 2003), the evaluation of PI_j values can be explained in several categories, namely:

0	≤	PIj	≤	1.0	Good condition according standard quality
1.0	<	PIj	≤	5.0	Lightly polluted
5.0	<	PIj	≤	10	Moderately polluted
PIj	>	10			Heavily polluted

3. RESULT AND DISCUSSION

The Blang Bintang Regional Landfill in Aceh Besar Regency serves as the final waste management site for two areas, namely Aceh Besar Regency and Banda Aceh City. The landfill's capacity continues to be under pressure due to the surge in annual waste generation, which has led to overload conditions. This increase in waste volume is triggered by changes in people's consumption patterns, which generate more waste. As a result, the production of leachate from waste piles also increases every month. The leachate that is formed is then channeled through a network of pipes to the inlet of the Leachate Treatment Plant (IPAL) at the landfill site to undergo treatment before finally being released into the environment.

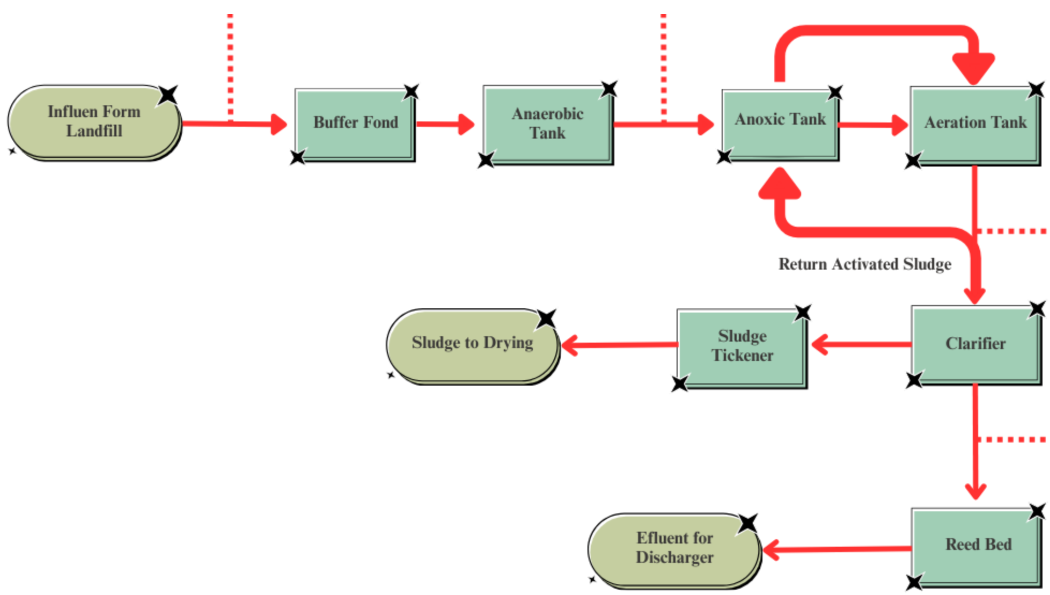


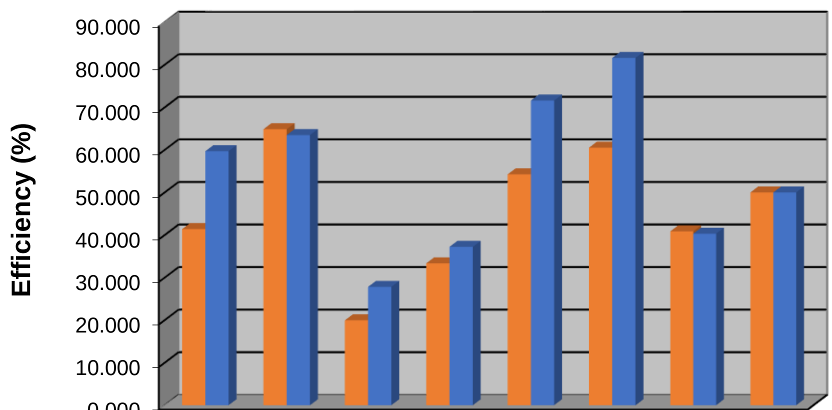
Figure 2. Leachate treatment process flowchart at Blang Bintang Landfill, Aceh, Indonesia

3.1. Technology Efficiency on Wastewater Treatment Plan Installation (IPAL)

The calculations of WWTP/IPAL performance efficiency show significant variations in achievement between parameters. During the observation period, removal efficiency for BOD and NH_3-N parameters was classified as efficient (60-80%), while TSS and nitrate were classified as moderately efficient (40-60%). However, the efficiency for the COD parameter was still inefficient (<40%), indicating that the aerobic biological process in the treatment unit was not yet optimal in degrading complex organic matter. These results reflect the WWTP's performance, which is not yet fully stable in handling fluctuating wastewater pollutant loads.

The efficiency of wastewater treatment technology at the Blang Bintang Regional Landfill is achieved through the application of gradual biological technology for optimal efficiency. The buffer pond serves to stabilize flow and pollutant loads. The anaerobic and anoxic stages sequentially degrade complex organic matter and break down nitrogen compounds. The clarifier separates biological sludge from treated water. The sludge is then thickened in a sludge thickener before being dried in a red bed pond. The integration of all these units creates a continuous process that improves pollutant removal efficiency, reduces the volume of final sludge, and ensures that the effluent meets quality standards.

The efficiency of WWTP performance is evaluated based on COD, BOD, nitrogen, and phosphate parameters. The results show that the installation successfully removed more than 90% of BOD and COD (Urbancl *et al*., 2025). The effectiveness of domestic IPAL by calculating the percentage decrease in pollutant concentration shows variations in effective performance for BOD (66.64%), COD (65.99%), TSS (46.85%), and Oil-Fat (61.64%), and is very effective for Ammonia (88.33%). However, the effectiveness is only moderately effective for Total Coliform (43.81%). The performance of IPAL is influenced by maintenance and compliance with SOPs (Setiadi *et al*., 2025).



	TSS	BOD	COD	Nitrat	NH3N	Cd	Fe	Hg
Dry Season	41.379	64.841	19.951	33.333	54.239	60.504	40.845	50.000
Wet Season	59.685	63.473	27.805	37.209	71.578	81.609	40.294	50.000

Figure 3. Result on efficiency percentage parameters on landfill's WWTP

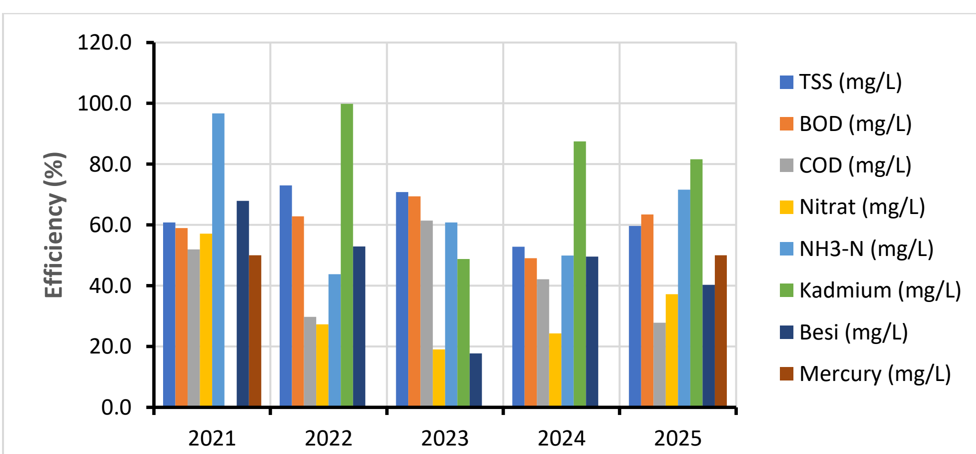


Figure 4. Percentage trend efficiency result on 5 year period from BPSR DLHK Aceh

The results of the calculation of pollutant removal efficiency at the Blang Bintang Regional Landfill Water Treatment Plant (IPAL) show significant variations in performance between the two observation periods in 2025. In Phase I, the highest efficiency was achieved by the BOD (64.84%) and Cd (60.50%) parameters, while COD showed the lowest performance (19.95%). In Phase II, there was an increase in efficiency for most parameters, especially NH_3-N, which increased dramatically from 54.24% to 71.58%, and Cd, which reached 81.61%, which is considered very efficient. However, the COD parameter still showed low efficiency (27.81%), and Fe remained relatively stagnant at around 40%. This indicates that the biological process and heavy metal precipitation (except Fe) are working quite well, but the treatment of complex organic compounds (reflected in COD) and iron precipitation remain operational challenges that need to be optimized to improve the overall performance of the IPAL.

Although the treatment system shows a decrease in the concentration of several pollutant parameters, the quality of the effluent produced still exceeds the applicable quality standards. Thus, the treatment plant cannot yet be categorized as environmentally effective, because the reduction in pollutant load has not been accompanied by compliace with the required quality standards.

Evaluation of the performance of the Wastewater Treatment Plant (WWTP) in reducing organic load, with a reduction in COD and BOD5 reaching 97.2%. However, the efficiency of total phosphate (TP) and total nitrogen (TN) removal was lower, at 49.4% and 57.6%, respectively. This results indicates that the primary and secondary treatment process have been effective, however, performance improvements are needed at the tertiary stage in order to fully meet wastewater quality standards (Shumbe *et al*., 2024). The high efficiency of the IPAL performance successfully maintained 100% removal of E. coli, average turbidity of 65.88–99.61%, and iron (Fe) of 82–99%, all of which meet WHO/SANS standards (Bwapwa *et al*., 2024).

Based on the figure 4, the Blang Bintang landfill wastewater treatment plant over five years, treatment performance shows mixed results. The efficiency of the TSS, BOD, nitrate, NH_3-N, and cadmium parameters has increased significantly and consistently from year to year. Conversely, the efficiency of COD and Iron (Fe) parameters has been relatively stagnant and tends to be low, indicating that the treatment process is still not optimal in degrading complex organic materials and metals of this type. Mercury (Hg) shows a fluctuation. The increase in efficiency in most parameters reflects improvements in the operation and maintenance of the IPAL unit during this period.

3.2. Water Quality Evaluation towards the Standard

The evaluation of river water quality around the landfill shows mixed results. For most physical and chemical parameters, such as temperature and pH, the measured values are still within the class II water quality standards according to Government Regulation No. 22 of 202 (Presiden RI, 2021). However, there are indications of exceedances for several organic and microbiological parameters at certain sampling points, especially at locations close to the IPAL effluent flow. This suggests the influence of leachate discharge on the receiving water body.

River water quality was evaluated by analysing physical-chemical parameters and heavy metals at the upstream, middle, and downstream sections, then comparing them with WHO quality standards. The results show that the water in the middle and downstream sections of the river is heavily polluted, with a Water Quality Index (WQI) >100. Parameters such as TDS, nitrate, BOD, Cd, and Fe far exceed WHO safety limits. This pollution is mainly caused by leachate seepage from nearby municipal solid waste disposal sites (Gyabaah *et al*., 2024; Omofunmi *et al*., 2020).

Based on the Table 1. the river water quality recapitulation data, it was identified that several key parameters had exceeded the established quality standards, especially at the sampling point downstream of the wastewater treatment plant. The concentrations of BOD, COD, and Total Coliform consistently show values above the Class II water quality standards as per Appendix VI Republic of Indonesia Government Regulation No. 22 of 2021, indicating serious organic and bacteriological pollution (Presiden RI, 2021). High ammonia (NH_3-N) values at several points also reinforce the suspicion of contamination from inadequately treated effluent. This pattern confirms that effluent from the IPAL has a significant impact on the degradation of river water quality in the surrounding area, requiring urgent management intervention.

Table 1. River water quality data monitoring result

Location	Parameter												
	Temp (ºC)	**pH**	**TSS (mg/L)**	**DO (mg/L)**	**BOD (mg/L)**	**COD (mg/L)**	**Nitrate (mg/L)**	**NH_3-N (mg/L)**	**Chlorine (mg/L)**	**Total Coliform (MPN/100 ml)**	**Cd (mg/L)**	**Fe (mg/L)**	**Hg (mg/L)**
Phase I Dry Season (10 July 2025)													
Point 1	26.5	7.40	24	6.80	2.40	20.78	8.02	0.06	0.01	590	0.00034	0.045	<0.0001
Point 2	26.5	8.74	**65**	**3.93**	**20.40**	**41.17**	**11.25**	**0.25**	0.02	1500	0.00036	**3.650**	<0.0001
Point 3	27.0	8.50	**54**	4.50	**10.00**	**28.00**	9.80	0.20	0.02	1300	0.00034	**2.050**	<0.0001
Point 4	28.5	8.04	**52**	4.40	**5.40**	24.00	8.50	0.08	0.03	1200	0.00036	**1.800**	<0.0001
Phase II Wet Season (16 Sept. 2025)													
Point 1	25.5	7.69	26.4	5.40	2.90	23.20	9.20	0.08	0.02	800	0.00036	0.050	<0.0001
Point 2	26.0	6.56	**68.0**	3.50	**30.00**	**62.00**	**14.00**	**0.45**	0.03	1700	0.00038	**4.210**	<0.0001
Point 3	26.0	6.42	**59.0**	4.20	**12.00**	**31.00**	**10.50**	**0.40**	0.03	1400	0.00036	**2.120**	<0.0001
Point 4	26.5	6.80	50.0	4.30	**8.60**	25.00	8.10	**0.36**	**0.04**	1300	0.00036	**1.900**	<0.0001
Stand. Dev	Dev 3	6-9	50	Min 4	3	25	10	0.2	0.03	5000	0.01	0.3	0.002

Note: Hg : < 0.0001 = Below the instrument detection

3.2.1. Total Suspended Solid (TSS)

Total Suspended Solids (TSS) are solid materials that are suspended in water and are the main cause of increased turbidity. Unlike sediments, TSS particles are smaller and lighter, such as clay particles, certain organic materials, and microorganism cells. In surface waters, clay particles can remain suspended for months before eventually undergoing destabilization due to the influence of other substances that trigger coagulation and sedimentation. Although under natural conditions, suspended and dissolved materials are generally non-toxic, excessive concentrations can significantly increase turbidity. This results in the obstruction of sunlight penetration into the water column and disrupts the photosynthesis process of aquatic organisms.

TSS is suspended solids that cause water turbidity and can inhibit sunlight penetration, thereby disrupting the photosynthesis process of aquatic organisms (Alfatihah *et al*., 2022). TSS is defined as solid material suspended in water and is the main cause of turbidity. TSS concentrations that exceed the threshold can block sunlight penetration into the water body, thereby disrupting the photosynthesis process of aquatic organisms. TSS measurement plays a crucial role in assessing the level of turbidity and quality of a water body.

Suspended solids consist of organic and inorganic components that float in the water medium and directly contribute to turbidity. The discharge of liquid waste with high TSS concentrations into open waters is not permitted, because in addition to potentially causing siltation, it can also limit light penetration to the bottom of the water body, thereby inhibiting the photosynthetic activity of microorganisms.

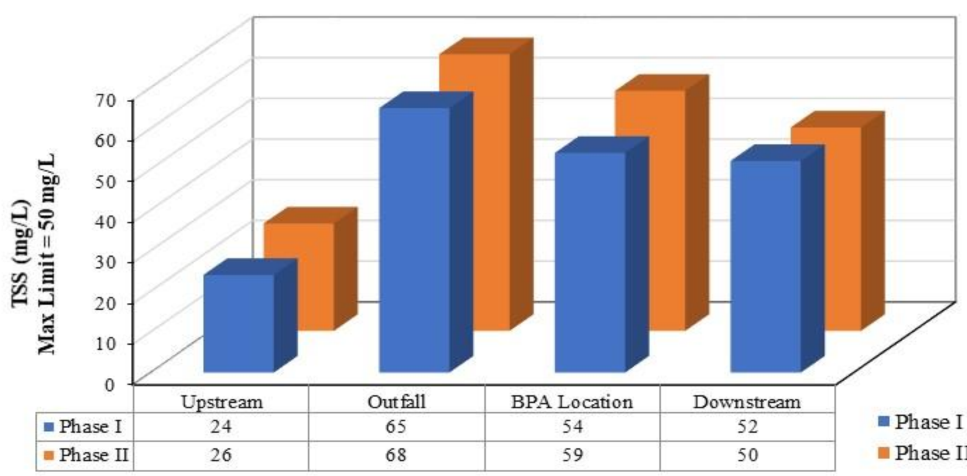


Figure 5. TSS standard quality comparison with the water quality standard

Test results show that TSS concentrations in the Krueng Uteun Siblah River exceed the established quality standards at several observation points. The increase in TSS values is caused by leachate containing organic and inorganic solid particles, as well as soil erosion from open landfill areas. Operational activities at the landfill, such as waste transportation, compaction, and material unloading, also generate dust and sediment particles that are carried by surface runoff.

3.2.2. Biological Oxygen Demand (BOD)

BOD is a parameter that measures the amount of oxygen required by aerobic microorganisms to break down organic matter contained in water into inorganic compounds, under specified conditions of time and temperature. BOD is a parameter that indicates the amount of dissolved oxygen required by aquatic biota to break down pollutants. A high BOD value (>10 mg/L) indicates water pollution, generally from domestic and industrial waste, as it reduces the dissolved oxygen that is vital for aquatic life (Zaman *et al*., 2023).

Wastewater with high BOD values discharged into natural water bodies will cause a decrease in dissolved oxygen concentration in the aquatic environment. A water body is said to have self-purification capacity if its dissolved oxygen availability is still sufficient to meet the needs of the biodegradation process of organic matter and the DO concentration can return to saturation levels similar to the initial conditions after receiving pollution loads.

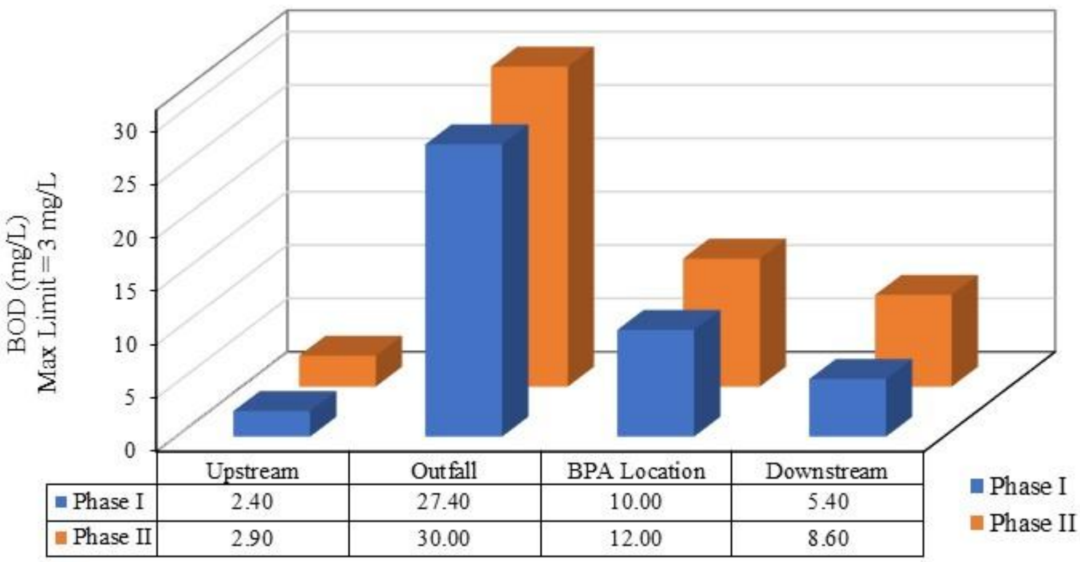


Figure 6. BOD standard quality comparison with the water quality standard

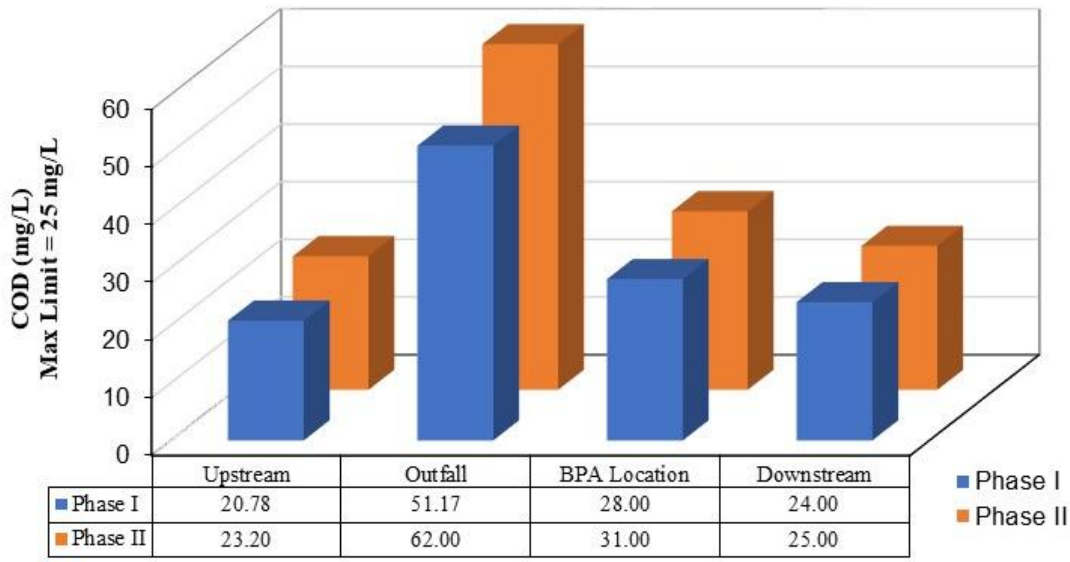
According to Figure 6, the BOD concentration in 3 (three) observation location in Krueng Uteun Siblah River at both observation phase showed figures that exceed the established quality standards. High BOD values in rivers around the landfill are caused by seepage or leachate containing organic compounds resulting from waste decomposition. This leachate is containing a large number of organic materials, thus increasing the oxygen demand for biological decomposition processes in the water.

3.2.3. Chemical Oxygen Demand (COD)

COD is an analytical parameter that measures the amount of oxygen (in mg O_2 per liter) consumed chemically to oxidize all organic and inorganic in the sample water. In the standard method, potassium dichromate ($K_2Cr_2O_7$) is generally used as a strong oxidizing agent. This parameter serves as an indicator to estimate the total load of pollutants, especially organic materials, in a water body.

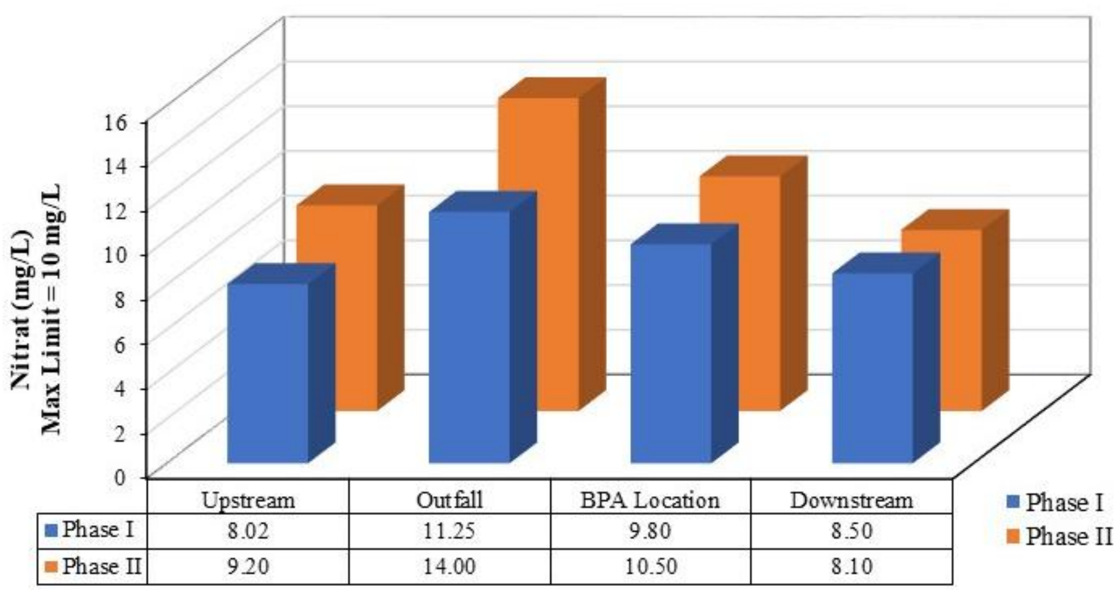
COD parameter showed the number of oxygens needed to oxidize the organic and inorganic matter chemically. High COD number indicate high levels of pollutants, which can degrade the water quality and disrupt aquatic ecosystems due to reduced dissolved oxygen (Dwangga & Farida, 2023). COD measures the oxygen required to degrade almost all organic compounds throguh chemical oxidation reactions, including componds resistant to microbial decomposition. Due to its broader coverage, the COD measurement value for a water sample is almost always higher than its BOD value.

Based on the Figure 7. COD concentrations at the outfall and BPA location exceeded the quality standards. High COD values along the river are primarily caused by leachate seepage, which contains organic and inorganic compounds resulting from waste decomposition. Rainwater dissolves pollutants from the waste piles and then flows into water bodies, increasing the pollution load and chemical oxygen demand (COD) in these waters.



	Upstream	Outfall	BPA Location	Downstream
Phase I	20.78	51.17	28.00	24.00
Phase II	23.20	62.00	31.00	25.00

Figure 7. COD standard quality comparison with the water quality standard



	Upstream	Outfall	BPA Location	Downstream
Phase I	8.02	11.25	9.80	8.50
Phase II	9.20	14.00	10.50	8.10

Figure 8. Nitrate standard quality comparison with the water quality standard

3.2.4. Nitrate (NO_3^-)

Based on Figure 8, two monitoring location in the Krueng Uteun Siblah River identified nitrate concentrations exceeding established quality standards. The increased nitrate levels in the waters surrounding the landfill could be caused by leachate seepage, which contains nitrogen compounds from the decomposition of organic waste, as well as contamination from poorly managed domestic waste and animal waste near the site.

Nitrate (NO_3^-) is a stable nitrogen compound that plays a vital role in protein synthesis in plants and animals. However, excessive nitrate concentrations in water can trigger eutrophication, characterized by uncontrolled algae growth, reducing dissolved oxygen levels and potentially killing aquatic life such as fish. Sources of nitrate include industrial waste, agricultural fertilizer applications, and chemicals such as paint.

Nitrate (NO_3^-) is an inorganic chemical commonly found in water due to agricultural activities and domestic waste. Excessive levels can be harmful to health, particularly triggering methemoglobinemia in infants. The maximum limit for nitrate in drinking water should be 45 mg/L (Pertiwi *et al*., 2023). High nitrate concentration in drinking water can cause serious, even fatal health impacts. This problem is often found in agricultural areas due to excessive fertilizer use, which then undergoes nitrification and contaminates water sources.

3.2.5. Ammonia (NH_3-N)

Ammonia (NH_3) is a nitrogen compound that, under low pH conditions, will turn into ammonium ions (NH_4^+). Its presence in surface waters generally comes from the excretion of living creatures (urine and feces) and the microbiological oxidation of organic materials originating from domestic waste, industry, and natural sources. High ammonia concentrations in rivers are a strong indicator of pollution.

Ammonia is a crucial chemical parameter in aquaculture. Its main sources are feed residues and biota excretion. Ammonia is toxic, especially in its non-ionic form, so its concentration must be managed and kept below the safe threshold for the health of cultivated organisms. This compound is toxic to aquatic biota such as fish and plankton, and can increase the pH of the aquatic environment. These changes have the potential to cause death to animal and plant organisms in the aquatic ecosystem.

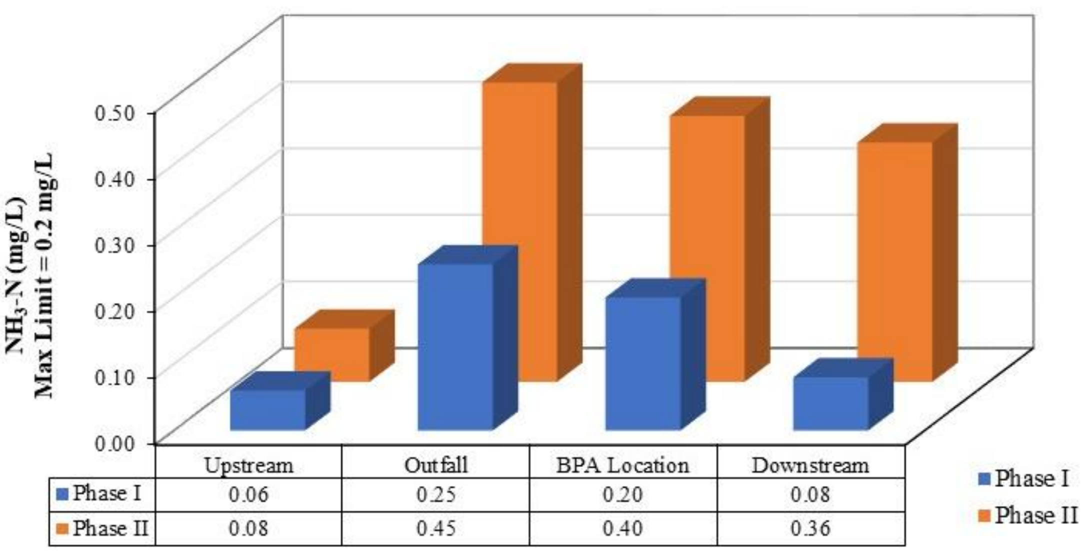


Figure 9. NH_3-N standard quality comparison with the water quality standard

Based on the graphical analysis of the data, it can be identified that the ammonia concentration at several monitoring points on the Krueng Uteun Siblah River has exceeded the established quality standards. The high ammonia levels in the river around the landfill site are mainly caused by leachate containing decomposed organic waste. The decomposition of organic waste in the landfill produces ammonia as the main product. Leachate that is not properly managed then pollutes the surrounding water bodies, significantly increasing ammonia concentrations.

3.2.6. Iron (Fe)

Leachate exposure from landfills can increase iron (Fe) concentrations in receiving water bodies. Leachate formed from waste decomposition is acidic and corrosive, thereby dissolving iron from the soil and inorganic waste materials. This dissolved iron is then carried by the flow into rivers, causing metal pollution that can disrupt aquatic ecosystems.

The iron (Fe) concentration at surface water points around the landfill (S1 and S3) reached 2 mg/L and 3 mg/L, respectively, which exceeded the Class I water quality standard of 0.3 mg/L. This indicates that leachate from the landfill has a significant effect on increasing iron levels in surrounding waters (Dwangga & Farida, 2023). Leachate from the Piyungan landfill contains 7.85 mg/L of iron (Fe), exceeding the regional quality standard of 2 mg/L. In the receiving water body, the highest iron concentration (0.7515 mg/L) was detected at the point closest to the leachate outlet, indicating a significant contribution of leachate to the contamination of this metal in surrounding waters (Astuti *et al*., 2023).

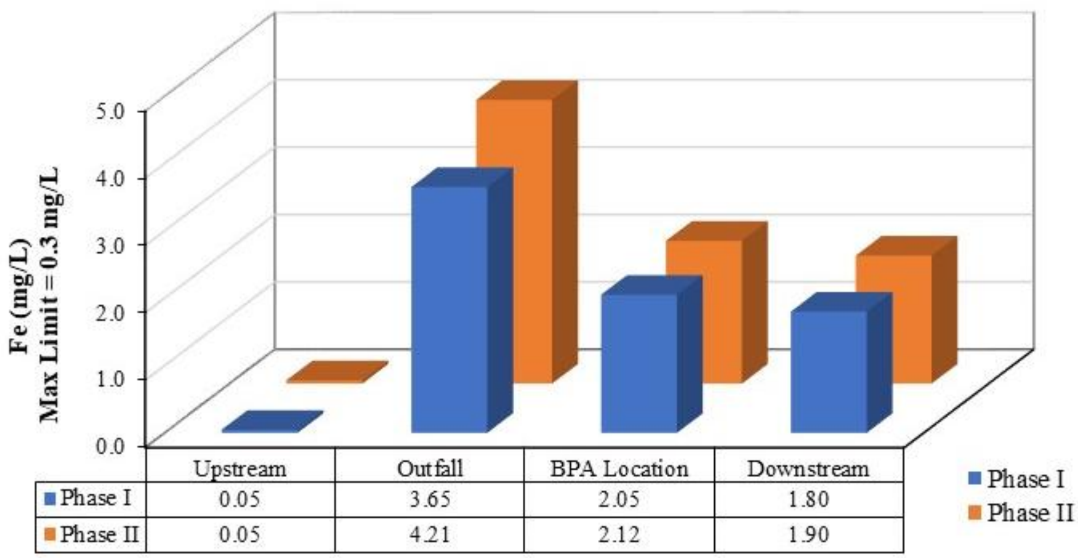


Figure 10. Iron standard quality comparison with the water quality standard

The graphical analysis indicates that the concentration of iron (Fe) at several monitoring points on the Krueng Uteun Siblah River exceeds the established quality standards. High iron (Fe) levels in rivers around landfills are mainly caused by leachate seepage. Leachate, which is acidic and corrosive, is formed from the decomposition of waste and can dissolve iron from the soil, waste material, and infrastructure at landfills. This iron-rich solution is then carried by the flow to receiving water bodies, increasing its concentration.

3.3. Pollution Index Calculation (IP)

The IP value tends to be higher during the rainy season than during the dry season. This is due to increased surface runoff carrying various pollutants such as sediment, domestic waste, and garbage from the landfill site to water bodies. Conversely, during the dry season, water flow is more stable and the dilution of pollutants is more effective, resulting in relatively better water quality and lower IP values, according to research conducted by (Pebiola *et al*., 2025). IP calculations between seasons show differences in pollution levels influenced by hydrological conditions. A comparison of IP values between seasons shows a tendency for IP values to be higher in the rainy season than in the dry season.

Table 2. IP Value Comparison Each Season

No	Location	Dry Season	Wet Season
1	Krueng Uteun Siblah Upstream	0.643	0.761
2	BPA	4.237	4.419
3	200 Meter from the Outfall	2.649	2.970
4	Krueng Uteun Siblah Downstream	1.687	2.431

From the results of IP calculations between seasons, it can be seen that at all monitoring locations, IP values in the rainy season tend to be higher than in the dry season. The comparison between upstream and downstream observation location shows an increase in the concentration of TSS, BOD, COD, NH_3-N, and Fe parameters, accompanied by a decrease in DO levels at the downstream location. These findings indicate the potential impact of effluent discharge on river water quality. Based on the Pollution Index (IP) calculation, the value at the downstream location was 2.43 which classified as slightly polluted, while at the upstream location it was 0.761, which is classified as good during the rainy season. The difference in IP values reinforce the indication of a decline in water quality in the downstream segment of the Krueng Uteun Siblah River. At the upstream of the Krueng Uteun Siblah River, the IP value remained in the good condition category despite an increase from 0.643 to 0.761. At the BPA location near the outfall, the IP value shows a higher level of pollution in both the dry and rainy seasons, with an increase from 4.237 to 4.419, reflecting an increase in pollutant load due to an increase in leachate volume during rainfall.

4. CONCLUSION

Based on the results of the study, it can be concluded that the leachate treatment plant at the Blang Bintang Regional Landfill shows varying performance in reducing pollutant concentrations. Although it is capable of reducing organic loads such as BOD, TSS, and several heavy metals with varying efficiency, the COD and iron (Fe) parameters still show low treatment efficiency and tend to be stagnant. The impact of effluent discharge that does not fully meet quality standards is clearly seen in the decline in water quality in the Krueng Uteun Siblah River, especially at the point around the outfall. There has been a significant increase in BOD, COD, and iron (Fe) parameters that exceed the threshold, accompanied by a decrease in dissolved oxygen (DO) levels. These findings indicate that even though the treatment process has been running, the performance of the installation is not yet optimal and the discharge of effluent continues to have a significant negative impact on the surrounding aquatic ecosystem. Therefore, optimization and improvement of the treatment system's performance are required, such as routine maintenance of the IPAL, maintenance of the piping network to prevent clogging, activation of the aerators in the aeration pond, addition of metal-absorbing plants in the red bed pond, and stricter monitoring to ensure that the effluent quality meets standards before being discharged into the environment.

AUTHOR CONTRIBUTION STATEMENT

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Jon	✓	✓				✓		✓	✓		✓			
IR	✓			✓		✓		✓	✓	✓		✓		
Suh	✓	✓				✓				✓		✓		
SM										✓	✓			
Mar										✓	✓			

C: Conceptualization	Fo: Formal Analysis	O: Writing - Original Draft	Fu: Funding Acquisition
M: Methodology	I: Investigation	E: Writing - Review & Editing	P: Project Administration
So: Software	D: Data Curation	Vi: Visualization	
Va: Validation	R: Resources	Su: Supervision	

REFERENCES

Alfatihah, A., Latuconsina, H., & Prasetyo, H.D. (2022). Analisis kualitas air berdasarkan paremeter fisika dan kimia di perairan Sungai Patrean Kabupaten Sumenep. *AQUACOASTMARINE: Journal of Aquatic and Fisheries Sciences*, ***1***(2), 76–84. https://doi.org/10.32734/jafs.v1i2.9174

Angrianto, N.L., Manusawai, J., & Sinery, A.S. (2021). Analisis kualitas air lindi dan permukaan di areal TPA Sowi Gunung dan sekitarnya di Kabupaten Manokwari Papua Barat. *Cassowary*, 4(2), 221–233.

Astuti, F.A., Syafrudin, S., & Susilowati, I. (2023). Kajian status mutu air sungai akibat buangan air lindi TPA Piyungan di Kabupaten Bantul. *Jurnal Ilmu Lingkungan*, ***21***(4), 881–887. https://doi.org/10.14710/jil.21.4.881-887

Bracamontes-Ruelas, A.R., Ibarra-Rodríguez, D., Rodríguez-Campos, J., Velázquez-Fernández, J.B., Reyes-Vidal, Y., & Reynoso-Cuevas, L. (2025). Evaluation of the presence of emerging contaminants in a municipal wastewater treatment plant in Durango, Mexico. *Case Studies in Chemical and Environmental Engineering*, ***11***, 101218. https://doi.org/10.1016/j.cscee.2025.101218

BSN (Badan Standardisasi Nasional). (2021). *SNI 8990:2021 - Metode Pengambilan Contoh Uji Air Limbah untuk Pengujian Fisika dan Kimia*. Badan Standardisasi Nasional, Jakarta.

Bwapwa, J.K., Mkhize, N., & Seyam, M. (2024). Evaluation of operational efficiency and performance for a water treatment plant. *South African Journal of Chemical Engineering*, ***49***, 11–34. https://doi.org/10.1016/j.sajce.2024.04.003

Chen, Z., Kurniawan, T.A., & Yap, P.-S. (2024). Integrating leachate treatment into circular economy landfill practices for nutrient, energy, and material (NEM) recovery and climate change mitigation. *Journal of Water Process Engineering,* ***68***, 106524. https://doi.org/10.1016/j.jwpe.2024.106524

Dari, H.W., & Suhartini. (2024). Dampak pengolahan air lindi terhadap kualitas air sungai dan sumur di sekitar TPA Regional Piyungan Yogyakarta. *Bioscientist: Jurnal Ilmiah Biologi,* ***12***(1), 71. https://doi.org/10.33394/bioscientist.v12i1.9601

Dwangga, M., & Farida, A. (2023). Pengaruh air lindi (*leachate*) terhadap kualitas air permukaan di sekitar TPA Kota Sorong. *EnviroScienteae,* ***19***(1). http://dx.doi.org/10.20527/es.v19i1.15759

Dwiratna, C., Setyobudiarso, H., Sudiro, & Artiyani, A. (2024). Perkembangan pengolahan lindi TPA: Tinjauan. *Jurnal Penelitian Multidisiplin,* ***3***(1).

Emalya, N., Tarmizi, Suhendrayatna, Munawar, E., Fellner, J., & Yunardi. (2024). Coupling electrochemical energy generation with leachate bioremediation in sediment microbial fuel cell reactors. *Case Studies in Chemical and Environmental Engineering,* ***10***, 100896. https://doi.org/10.1016/j.cscee.2024.100896

Gunarathne, V., Phillips, A.J., Zanoletti, A., Rajapaksha, A.U., Vithanage, M., Di Maria, F., Pivato, A., Korzeniewska, E., & Bontempi, E. (2024). Environmental pitfalls and associated human health risks and ecological impacts from landfill leachate contaminants: Current evidence, recommended interventions and future directions. *Science of The Total Environment,* ***912***, 169026. https://doi.org/10.1016/j.scitotenv.2023.169026

Gyabaah, D., Awuah, E., Kuffour, R.A., Antwi-Agyei, P., Wiafe, S., & Asiedu, S.B. (2024). Assessment of dumpsites leachate, geotechnical properties of the soil, and their impacts on surface and groundwater quality of Sunyani, Ghana. *Environmental Advances,* ***16***, 100548. https://doi.org/10.1016/j.envadv.2024.100548

Hu, B., Zhou, M., Zhang, K., Lu, J., Qin, Y., Tan, Y., Hu, H., Tian, S., & Gu, X. (2024). The advanced treatment of mature landfill leachate by iron-carbon micro-electrolysis combined with persulfate activated (ICME-PS) process. *Journal of Environmental Chemical Engineering*, ***12***(5), 113786. https://doi.org/10.1016/j.jece.2024.113786.

Lestari, D.S. (2020). Evaluasi kinerja instalasi pengolahan air limbah domestik (studi kasus: IPAL domestik Waduk “X”, Jakarta). *Jurnal Sumber Daya Air,* ***16***(2), 91–102. https://doi.org/10.32679/jsda.v16i2.653

Mardizal, J., Rizal, F., & Syah, N. (2024). *Manajemen kualitas air*. Eureka Media Utama.

Menteri LHK (Lingkungan Hidup dan Kehutanan). (2016a). *Peraturan Menteri Lingkungan Hidup dan Kehutanan Nomor 59 Tahun 2016 tentang Baku Mutu Lindi bagi Usaha dan/atau Kegiatan Tempat Pemrosesan Akhir Sampah*. Kementerian Lingkungan Hidup dan Kehutanan, Jakarta.

Menteri LHK (Lingkungan Hidup dan Kehutanan). (2016a). *Peraturan Menteri Lingkungan Hidup dan Kehutanan Nomor P.68/Menlhk/Setjen/Kum.1/8/2016 tentang Baku Mutu Air Limbah Domestik*. Kementerian Lingkungan Hidup dan Kehutanan, Jakarta.

MNLH (Menteri Negara Lingkungan Hidup). (2003). *Keputusan Menteri Negara Lingkungan Hidup Nomor : 115 Tahun 2003 Tentang Pedoman Penentuan Status Mutu Air*. KemMenterian Negara Lingkungan Hidup, Jakarta.

Meyrita, M., Sandria, F.S., Najmi, I., Firdus, F., Rizki, A., & Nasir, M. (2023). Kontaminasi logam berat pada air sumur warga akibat air lindi dari Tempat Pemrosesan Akhir (TPA). *Jurnal Teknologi Lingkungan Lahan Basah*, ***11***(2), 2023: 425 - 433 https://doi.org/10.26418/jtllb.v11i2.64052

Nurbaya, F., & Sari, D.P. (2023). *Parameter air dan udara serta uji kualitas air sungai*. PT Arr Rad Pratama.

Omofunmi, O., Satimehin, A., Oloye, A., & Umego, O. (2020). Effect of landfill leachates on some water quality indicators of selected surface water and groundwater at Ilokun, Ado-Ekiti, Nigeria. *Makara Journal of Technology, **24***(2). https://doi.org/10.7454/mst.v24i2.3881

Pebiola, I.A., Mulyanti, H., & Rahmawati, L.A. (2025). Assessment of Bengawan Solo River raw water quality using the pollution index. *ANALIT: Analytical and Environmental Chemistry, **10***(1).

Pertiwi, N., Purnomo, T., Bao Balabuana, G., Rahmawati, Alfakihuddin, M.L.B., Makmur, A., & Rudyarti, E. (2023). *Parameter labor lingkungan*. PT Global Eksekutif Teknologi.

Presiden RI. (2021). *Peraturan Pemerintah Nomor 22 Tahun 2021 tentang Penyelenggaraan Perlindungan dan Pengelolaan Lingkungan Hidup*. Lembaran Negara Republik Indonesia Tahun 2021 Nomor 32.

Prisilla, C., Insani, I.N., Murtin, M., Rizky, M., Nurlina, N., Syamsia, S., Arsat, Y., Yusuf, H., & Yani, A. (2024). Analisis dampak pencemaran lindi tempat pemrosesan akhir (TPA) Desa Jononunu terhadap kualitas air dan lingkungan perkebunan: Studi literatur. *Jurnal Kolaboratif Sains*, ***7***(5), 1806–1812.

Sahabuddin, E.S. (2015). *Filosofi 'Cemaran' Air*. PTK Press, Kupang. ISBN 978-602-9222-08-1

Setiadi, A., Suswati, D., & Diba, F. (2025). Efektivitas instalasi pengolahan air limbah (IPAL) domestik di Laboratorium Klinik X (studi kasus Laboratorium Klinik X Kota Pontianak). *Jurnal Teknologi Lingkungan Lahan Basah, **13***(1), 41–50.

Sheng, B., Liu, S., Xiong, K., Liu, J., Zhu, S., & Zhang, R. (2024). Microbial community dynamics in different floc size aggregates during nitrogen removal process upgrading in a full-scale landfill leachate treatment plant. *Bioresource Technology, **413**,* 131484. https://doi.org/10.1016/j.biortech.2024.131484

Shumbe, T., Angassa, K., Tessema, I., Tibebu, S., Abewaa, M., & Getu, T. (2024). Performance evaluation of a brewery wastewater treatment plant: A case of Heineken Brewery, Addis Ababa, Ethiopia. *Heliyon, **10***(23), e40719. https://doi.org/10.1016/j.heliyon.2024.e40719

Tchobanoglous, G., & Metcalf & Eddy. (1991). *Wastewater engineering: Treatment, disposal, and reuse* (3rd ed.). McGraw-Hill. https://books.google.co.id/books?id=HR9SAAAAMAAJ

Urbancl, D., Hochenauer, C., Zachl, A., Fekonja, N., Petrovic, A., Goricanec, D., & Simonic, M. (2025). Zero-waste strategy of small wastewater treatment plants with integrated thermal treatment of generated solid wastes. *Energy, **337***, 138740. https://doi.org/10.1016/j.energy.2025.138740

Vidal, B., Kinnunen, J., Hedström, A., Heiderscheidt, E., Rossi, P., & Herrmann, I. (2023). Treatment efficiency of package plants for on-site wastewater treatment in cold climates. *Journal of Environmental Management, **342***, 118214. https://doi.org/10.1016/j.jenvman.2023.118214

Yuan, Y., Liu, J., Gao, B., & Sillanpää, M. (2022). Landfill leachate treatment in-depth by bio-chemical strategy: Microbial activation and catalytic ozonation mechanism. *Chemical Engineering Journal, **444***, 136464. https://doi.org/10.1016/j.cej.2022.136464

Zaman, N., Nasution, N.H., Iswahyudi, Susilawaty, A., Sitorus, E., Mohamad, E., Rodhiyah, Z., Syam, M.A., Murtini, S., Rois, I., Tangio, J.S., Rudiansyah, & Haryanti, S. (2023). *Manajemen kualitas air*. Yayasan Kita Menulis.