

Performance Evaluation of the Leachate Treatment Plant at the Bongkang Landfill in Tabalong District

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ABSTRACT

The performance of the Leachate Treatment Plant (LTP) is crucial to ensure that leachate meets the quality standards in Regulation No. P.59/2016 and to support the national targets of 30% waste reduction and 70% managed waste by 2025 (Presidential Regulation No. 97/2017). Without proper leachate treatment, waste management at landfills can cause secondary environmental problems. At the Bongkang Landfill in Tabalong District, an LTP has been installed, but its effectiveness in treating leachate has not yet been comprehensively evaluated. This study focuses on removal efficiency of BOD, COD, TSS Total Nitrogen, Mercury and Cadmium, with the aim of Analyzing the efficiency performance of the wastewater treatment plant (WWTP) since it began operating until it reached saturation point to determine the decline in its ability to treat leachate. Water samples were taken at the inlet and outlet of the Bongkang landfill using a collection method involving sample bottles, and were then analysed at an accredited laboratory in accordance with the research parameters. The result shows that the removal efficiency of WWTP in 2024 is still within a good range, with showing effective performance with fairly high BOD, COD, TSS, and total nitrogen removal

efficiencies. However, the drastic decline that occurred in 2025 indicates that the system has reached saturation, where biological and physical processes are no longer optimal. The decline occurs in almost all leachate treatment parameters, especially BOD and COD, which are the main indicators of leachate treatment quality. It is recommended that routine maintenance and optimisation of the treatment system at the Bongkang landfill be carried out to maintain removal efficiency above 70%.

Keywords: Leachate Treatment Plant, Bongkang Landfill, Removal Efficiency

INTRODUCTION

The issue of waste is crucial in sustainable environmental development. As the population and consumption activities increase, the volume of waste continues to grow every year (Fitri & Setiawan, 2025). Waste management is also a crucial challenge in various regions, including Tabalong District, South Kalimantan Province. With a population of more than 260,000, it is estimated that domestic waste reaches around 55,000 tonnes per year, or 150 tonnes per day. Most of this volume ends up at the Bongkang Landfill, which is currently the only district-scale waste disposal site. Based on data from the

Tabalong Environment Agency (2024), the Bongkang Landfill has been serving 12 sub-districts and is experiencing overload with waste piles reaching a height of 15 metres.

The main problem caused by the accumulation of waste is the formation of leachate, which is a thick black liquid resulting from the decomposition of organic waste and the seepage of rainwater through piles of waste. Leachate is generally defined as a percolation liquid containing various organic and inorganic pollutants, heavy metals, and microorganisms (Sarwono et al., 2017).

Leachate is classified as hazardous and toxic waste (B3) that is very difficult to break down naturally. The amount and discharge of leachate produced as operational waste from landfills can increase in line with the increase in waste output (Hartini & Yulianto, 2018). Leachate production is inevitable, and landfills are an important infrastructure for urban growth. Leachate is created when rainfall seeps through the landfill and collects at the bottom. Leachate is a by-product of several physical, chemical, and biological processes. Many variables, including waste type, rainfall amount, hydrology, and landfill age, influence the general properties of leachate (Mahtab et al., 2021).

Leachate Treatment Plants (LTPs) are built to address these issues and serve as treatment systems specifically designed to reduce the content of pollutants in leachate before it is discharged into the environment. However, the effectiveness of LTPs is highly dependent on their design, the technology used, the volume of leachate treated, and the operational management applied (Harman et al., 2020). The leachate management process involves collection, monitoring, and treatment before discharge into the environment. The leachate collection system uses a drainage system or collection wells designed to collect water that seeps from

solid waste. The leachate is then channelled to wastewater treatment plant (WWTP) treatment facilities, such as physical-chemical treatment systems, biological processes, or thermal treatment, to remove or reduce the contaminants contained therein (Kahar et al., 2017).

The performance of the LTP is crucial to ensure that the leachate produced meets the quality standards set out in Regulation of the Minister of Environment and Forestry of the Republic of Indonesia No. P.59/MENLHK/SETJEN/KUM.1/7/2016.

LTP also plays a strategic role in supporting the national target of reducing waste by 30% and managing 70% of waste by 2025, as stated in Presidential Regulation No. 97 of 2017 concerning National Policy and Strategy for Domestic Waste Management. Without the proper treatment of leachate, overall waste management becomes incomplete and risks creating secondary problems such as environmental degradation. The Bongkang landfill in Tabalong District is one of the final waste management facilities equipped with an LTP. However, to date, there has been no comprehensive evaluation of the effectiveness of the IPL's performance in treating leachate at that location.

MATERIALS & METHODS

The study was conducted in Tabalong District, focusing on the Bongkang Landfill. Water sampling was conducted during the rainy and dry seasons between January 2024 and September 2025. Samples were taken at the inlet and outlet of the Bongkang landfill using a collection method involving sample bottles, and were then analysed at an accredited laboratory in accordance with the research parameters. The following are the Bongkang Landfill Site and LTP Layout.



Figure 1. Bongkang Landfill Site

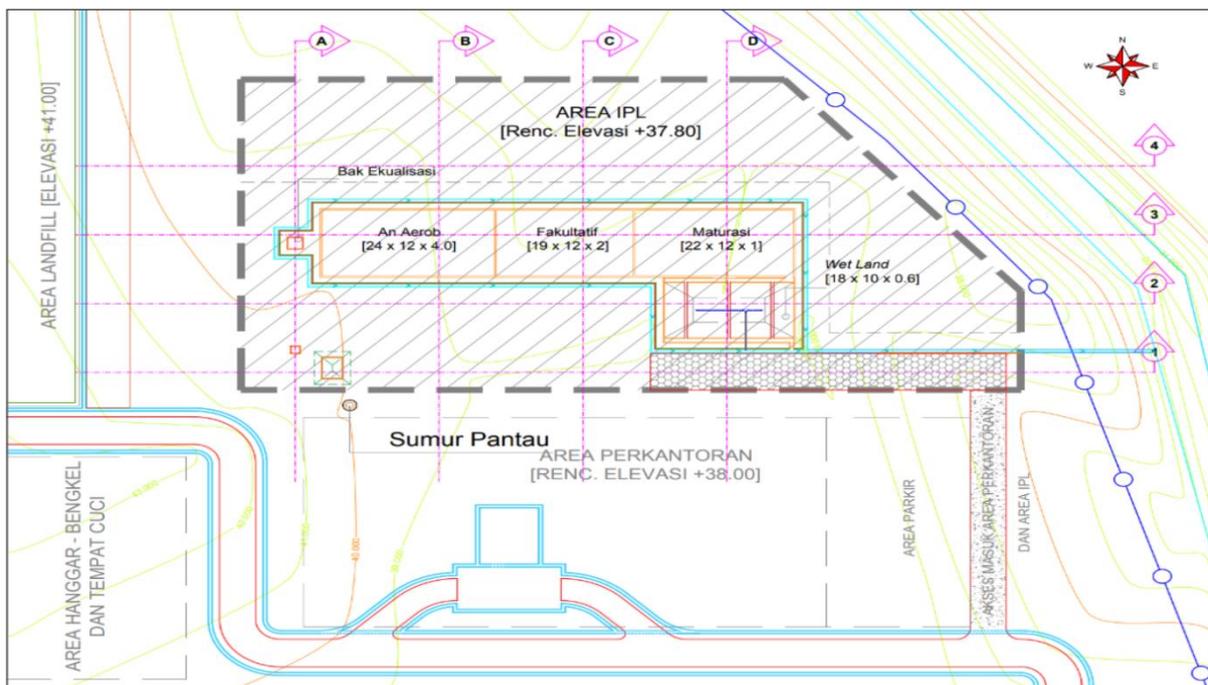


Figure 2. LTP Layout

To determine the rainy and dry seasons, rainfall data is required. According to Dayantolis et al. (2016), the criteria for the rainy and dry seasons can be seen from the monthly rainfall, where <150 mm is

considered the dry season and >150 mm is considered the rainy season. Rainfall data can be seen in Graph below.

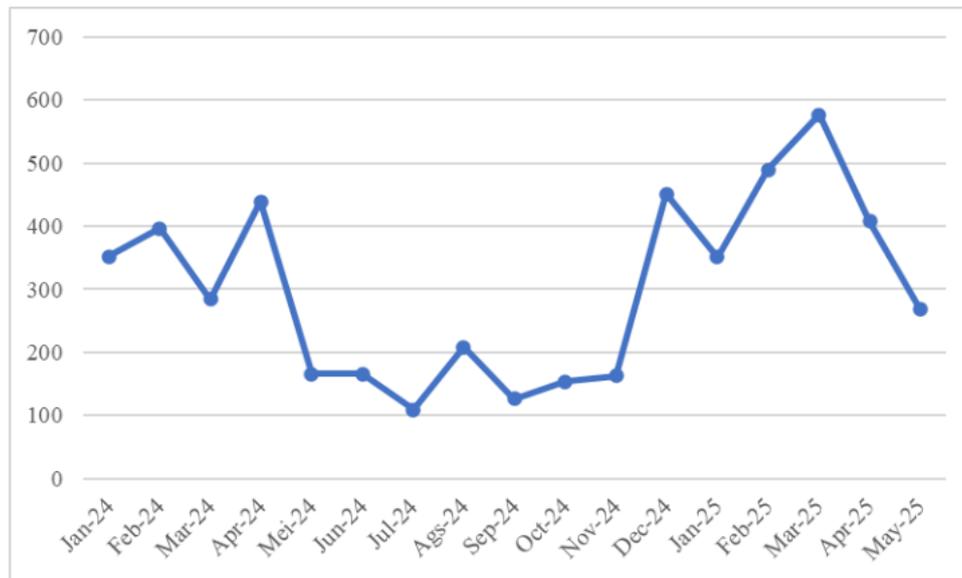


Figure 3. Monthly Rainfall Trends in Tabalong District for 2024–2025

Source: Center for Hydrometeorology and Remote Sensing Januari 2024 – Mei 2025

Based on Figure 3, from January 2024 to May 2025, the average rainfall is above 150 mm, indicating the rainy season, except for July and September 2024, which experience a dry season with rainfall below 150 mm.

The research parameters used are based on Minister of Environment Regulation No. P.59/Menlhk/Setjen/Kum.1/7/2016, as follows.

Table 1. Research Parameters

Parameters	Quality Standards	Unit
pH	6-9	-
BOD	150	mg/L
COD	300	mg/L
TSS	100	mg/L
Total Nitrogen (Total N)	60	mg/L
Mercury	0.005	mg/L
Cadmium	0.1	mg/L

Source: Minister of Environment Regulation No. P.59/Menlhk/Setjen/Kum.1/7/2016

The performance of WWTP can be calculated using the following formula:

$$RE (\%) = \frac{S_o - S}{S} \times 100\%$$

Description:

RE : Removal Efficiency (%)

S_o : Inlet Concentration (Wastewater influent (mg/L))

S : Outlet Concentration (Wastewater effluent (mg/L))

There are five categories of WWTP efficiency. The five categories of WWTP are as follows:

Table 2. Wastewater Treatment Plant (WWTP) Efficiency Category

Category	Range of Numbers
Very efficient	>80%
Efficient	60% - 80%
Moderate	40% - ≤60%
Poor	20% - ≤40
Inefficient	≤20%

Source: (Widiya *et al.*, 2024)

RESULTS

The removal efficiency (RE) calculation is performed to determine the WWTP's ability to reduce the concentration of each pollutant parameter between the inlet and outlet conditions.

The RE value is obtained using the formula of the difference between the inlet and outlet concentrations divided by the inlet concentration. The RE of WWTP can be seen in the following table.

Table 3. Removal Efficiency of Wastewater Treatment Plant (WWTP)

Year	Month	BOD		COD		TSS		Total N		Mercury		Cadmium	
		RE (%)	Cat	RE (%)	Cat	RE (%)	Cat	RE (%)	Cat	RE (%)	Cat	RE (%)	Cat
2024	Jan	70.99	E	71.35	E	48.55	M	83.62	VE	0,00	I	0,00	I
	Feb	-	-	-	-	-	-	-	-	-	-	-	-
	Mar	-	-	-	-	-	-	-	-	-	-	-	-
	Apr	-	-	-	-	-	-	-	-	-	-	-	-
	Mei	-	-	-	-	-	-	-	-	-	-	-	-
	Jun	-	-	-	-	-	-	-	-	-	-	-	-
	Jul	-	-	-	-	-	-	-	-	-	-	-	-
	Aug	2.64	I	2.64	I	8.06	I	32.57	P	0.00	I	0.00	I
	Sep	-	-	-	-	-	-	-	-	-	-	-	-
	Oct	89.44	VE	89.44	VE	88.78	VE	97.68	P	0.00	I	0.00	I
	Nov	25.94	P	25.96	P	-67.76	I	17.25	P	0.00	I	-8.82	I
Dec	75.73	E	75.73	E	84.69	VE	73.97	E	0.00	I	99.69	VE	
2025	Jan	-	-	-	-	-	-	-	-	-	-	-	-
	Feb	60.70	E	89.19	VE	9.49	I	76.00	E	-	-	0.00	I
	Mar	14.23	I	11.27	I	56.60	M	65.94	E	-	-	-100.00	I
	Apr	6.52	I	15.82	I	5.60	I	75.56	E	-	-	0.00	I
	Mei	48.92	M	13.32	I	53.69	M	50.00	M	-	-	0.00	I
	Jun	48.92	M	13.32	I	53.69	M	50.00	M	-	-	0.00	I
	Jul	-34.62	I	-8.47	I	53.80	M	-160.00	I	-	-	0.00	I
	Aug	1.74	I	19.35	I	51.53	M	-108.33	I	-	-	0.00	I
	Sep	52.12	M	26.00	I	32.24	P	-153.85	I	-	-	0.00	I

(Source: Secondary and Primary Data, 2025)

Description:

VE : Very efficient

E : Efficient

M : Moderate

P : Poor

I : Inefficient

Cat : Category

- : No data

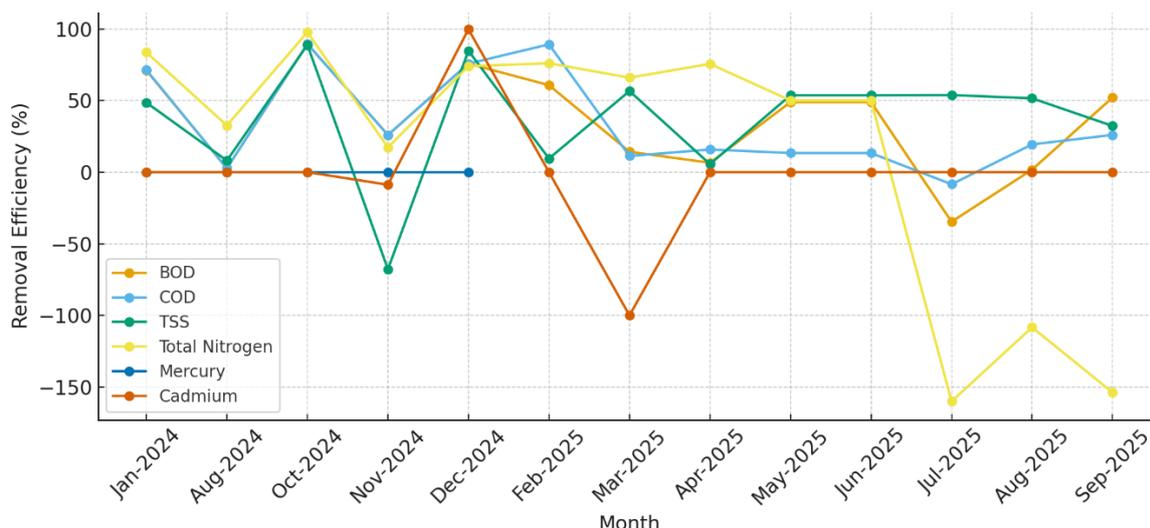


Figure 4. Trend of Research Parameters Removal Efficiency at the Leachate Treatment Plant in 2024–2025

The WWTP performed well in early 2024. All parameters showed high efficiency and stability. A steady decline began in mid-2025, particularly evident in the decrease in BOD and COD, instability in TSS, and a drastic decrease in Total N (the strongest indicator). Signs that the WWTP is entering a saturated condition are evident from negative efficiency, high fluctuations, and outlet values approaching or exceeding inlet values for several parameters. Mercury and cadmium values are very small, with minor changes not visible, resulting in a flat graph. However, negative efficiency does not mean that the WWTP has failed, but rather that there are minor fluctuations in the data.

DISCUSSION

Based on Table 4.2 and Figure 4, it can be seen that the system performance experienced a significant decline in almost all test parameters. The RE value was obtained using the formula of the difference between the inlet and outlet concentrations divided by the inlet concentration.

BOD

BOD removal efficiency indicates how well the LTP reduces the biodegradable organic load from the inlet to the outlet. The average efficiency in 2024 is around 53%, so in

general, BOD removal performance this year can be categorised as ‘moderate’, while the average efficiency in 2025 is only around 25%, a sharp decline compared to 2024. In general, the performance in 2025 can be categorised as ‘poor’. When all available data is combined, the average BOD removal efficiency is around 36%. This means that overall, the LTP only reduces one-third of the BOD load, which is still far from the ideal performance of leachate treatment.

In 2024, performance tended to be good but was not yet stable. Jan-24 70.99% (efficient) and Dec-24 75.73% (efficient) showed that LTP was able to achieve BOD removal efficiency above 70% under optimal operating conditions. Oct-24 89.44% (very efficient) even approached maximum performance. In 2025, there was a decline in efficiency and months with negative efficiency. Only Feb-25 at 60.70% met the efficient category. May, June, and Sep-25 (49–52%) were classified as moderately efficient, indicating moderate BOD reduction, but often insufficient to lower concentrations below quality standards. March, April, July, and Aug-25 are classified as inefficient, with very low to negative efficiency in Jul-25 (–34.62%), meaning that BOD at the outlet is higher than at the inlet. Sari et al. (2023) state that this increase in BOD at the outlet can occur due to the resuspension of biomass or sludge in the

biological unit/pond, which increases the dissolved BOD load; a decrease in microorganism capacity, for example due to high salinity, toxicity, or nutrient imbalance, so that organic matter is not degraded and is instead released back into the water; and the leachate becoming 'older': BOD/COD decreases (<0.3), reducing the biodegradable fraction and making it increasingly difficult for the biological process to achieve high efficiency.

The decline in average efficiency from 53% (2024) to 25% (2025) supports the assumption that both operational factors and leachate properties are changing in a direction that is less favourable for the pure biological process. However, in Aug-2024 (2.64%, inefficient) and Nov-2024 (25.94%, poor), there was a sharp decline in efficiency, indicating operational problems such as shock loading, aeration disruption, excessively short residence time, or flow bypass. BOD and COD showed the most significant decline, indicating a decrease in microorganism activity and biodegradation process effectiveness, possibly due to increased organic load or fouling of the reactor media. The decrease in efficiency may have occurred due to a sudden change in the organic load, which often occurs in active landfills, or it may have been caused by a decline in biological process performance, such as suboptimal aeration tanks, insufficient oxygen supply, or decreased microorganism activity. Research by Tunçsiper (2019) shows that BOD removal efficiency is greatly influenced by the stability of the organic load and microbial conditions, minor disturbances can drastically reduce efficiency.

COD

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COD efficiency range of 20–60% in old leachate using a conventional biological system. This drastic decline indicates that the wastewater treatment plant studied had reached saturation or biological degradation, resulting in a reduction in the ability of microorganisms to degrade organic matter.

Anoxic-aerobic Moving Bed Biofilm Reactor (MBBR) for leachate from the Cipayung landfill with an initial COD of 3,345–6,000 mg/L. The COD removal efficiency obtained was 59–67% at an HRT of 12 hours and 62–70% at an HRT of 24 hours. A well-designed system is generally capable of maintaining a consistent COD efficiency of around 60–70%. In a study (Pramesti & Mirwan, 2023) using a subsurface flow constructed wetland with *Typha angustifolia* plants, the COD removal efficiency of leachate can reach ± 90 –95% under optimal flow and plant density conditions. This indicates that the combination of filtration, media adsorption, and plant/microbial activity can produce very high efficiency, similar to the 'very efficient' in this study (Oct-2024 and Febr-2025).

TSS

The removal efficiency of TSS was very high on Oct-24, namely 1,110 (inlet) and 124.5 mg/L (outlet), resulting in a removal value of $\pm 89\%$. On Dec-24, it was 565 (inlet) and 86.5 mg/L (outlet), resulting in a removal value of $\pm 85\%$. Furthermore, for Jan-24 and Mar-May-Aug-Sep-25, the removal rate ranged from $\pm 32\text{--}54\%$. In Aug-24, Feb-25, and Apr-25, the removal rate was low, below 10%. One month showed an increase in TSS at the outlet, from 152 mg/L (inlet) in Nov-24 to 255 mg/L (outlet), which is -68% , meaning that the solids at the outlet were actually higher. On average, removal efficiency ranged from 37% to 46%, meaning the IPL can reduce TSS, but it is still unstable, occasionally causing effluent TSS to exceed inlet levels.

Fluctuations in TSS outlet can be caused by hydraulic shock due to heavy rain that disrupts sedimentation. Excessive agitation or aeration that lifts sludge from the bottom of the pond. Floc release in coagulation/flocculation units or biological units that are not yet mature. A decrease in efficiency can be caused by disturbances in the sedimentation process, such as excessive flow velocity, sludge accumulation, or a decrease in flocculation effectiveness. Hirom & Devi's (2019) research states that TSS is greatly influenced by hydraulic conditions and sedimentation tank design, overload or turbulence causes efficiency to decrease.

The efficiency of TSS removal in WWTP generally ranges from 40–70%, depending on the sedimentation and filtration systems used. The decrease in TSS efficiency is likely due to a decrease in the effectiveness of physical units such as sedimentation tanks or an increase in solid load in the influent. TSS efficiency of 55–70% in communal WWTPs with a multi-stage sedimentation system. This difference is thought to be due to suboptimal hydraulic design and sludge removal frequency in the system studied.

Total N

The total nitrogen removal efficiency at the wastewater treatment plant describes the percentage of nitrogen that is successfully

removed from the influent before it is discharged as effluent. Total nitrogen removal efficiency fluctuates greatly, ranging from 17–98%. When the influent load is very high, for example 2,431 mg/L in Oct-2024, the WWTP is actually capable of removing nitrogen with high efficiency, but in Aug and Nov-2024, its performance declined so that the outlet still exceeded 60 mg/L. This could be related to changes in leachate discharge, sludge age, biological tank conditions, or operational disturbances. In Feb–Jun 2025, when the total nitrogen inlet was still around 4.5–13.8 mg/L, the WWTP removal efficiency was around 50–76% and the outlet was below 5 mg/L. In Jul–Sep 2025, the inlet value was very low (1–1.3 mg/L) while the outlet was slightly higher (2.5–3.3 mg/L). This could be due to variations in the location/time of inlet and outlet sampling, the effect of mixing with effluent flow from other cells, or laboratory analysis uncertainty.

Pramesti & Mirwan (2023) applied a constructed wetland with water jasmine (*Echinodorus palaefolius*) for leachate and achieved a reduction in Total N of up to 89.6% at a flow rate of 5 L/day with a retention time of 14 days. A review of various constructed wetland studies for wastewater disposal indicates a general nitrogen removal efficiency range of 40–70%, with higher values achieved when design and operation are optimised. In this study, the efficiency values were higher than those in the above studies. The highest efficiency was on Oct-24 around 98%, and produced an outlet of <60 mg/L even though the inlet was 2,431 mg/L – this shows that technically the system is capable of working very well when operating conditions are optimal. Efficiency in early 2025 (50–76%) was within the general range for constructed wetlands/biological WWTP, but because the inlet concentration was already very low (4.5–13.8 mg/L), the effluent of 1–5 mg/L was already very safe from an environmental perspective.

Significant monthly fluctuations in efficiency indicate that the system is highly

influenced by changes in wastewater load, flow rate, and possibly sludge management or aeration. The literature emphasises the importance of hydraulic retention time, carbon availability for denitrification, and microbial community stability in maintaining high nitrogen efficiency (Li et al., 2021). Oct-24 had high total nitrogen inlet but nearly 98% removal efficiency. This indicates that the WWTP is designed to treat high-concentration wastewater, so the focus of improvement is more on operational stability than technological changes. In Jul–Sep 2025, although calculations showed ‘inefficiency’, the outlet concentration remained below the quality standard and was very small. Omidinia-Anarkoli & Shayannejad (2024) reported that negative values better describe the internal dynamics of the reactor and the uncertainty of the analysis rather than actual ‘nitrogen addition’ by the WWTP. This approach is commonly used in CW research when there is an increase in nitrate at the outlet due to nitrification.

Mercury

The mercury in this study (0.0007 mg/L) was in the lower range and did not exceed the quality standard. At concentrations close to the detection limit of the instrument, small differences between inlet and outlet are often undetectable, resulting in a calculated efficiency of 0%, even though there may be a small actual decrease. Biological units (activated sludge, MBBR, aeration ponds) are generally designed to reduce BOD, COD, TSS and ammonia, not specifically for mercury. Heavy metals are usually only indirectly removed through adsorption on sludge or flocs. Studies on several WWTP show that heavy metals do accumulate in sludge, not in treated water.

Using efficiency removal calculations, a mercury efficiency value of 0% does indeed fall into the ‘inefficient’ category. However, as long as the mercury concentration at the outlet remains <0.005 mg/L, the environmental risk from mercury through leachate is still relatively low and is not a

critical parameter at this time. Nurfahasdi et al (2025) studied the treatment of Terjun landfill leachate using electrocoagulation with iron electrodes. Through optimisation of voltage, electrode distance, and contact time, mercury removal efficiency reached $\pm 98.9\%$, and the final mercury concentration was below the quality standard. This is an example of a process specifically designed to remove mercury, resulting in efficiency far above 80% (the very efficient category).

Cadmium

The research results show that the WWTP has not consistently removed cadmium from leachate, except in one case of high load (Dec-2024) where the removal efficiency was very high. In Jan, Aug, Oct 2024, the efficiency was 0% (inefficient). This occurred because the inlet and outlet values were the same (e.g., 0.0015 mg/L \rightarrow 0.0015 mg/L). This means that the WWTP acts more as a ‘pass through’ rather than an active removal unit. It is still safe in terms of regulations because the outlet concentration is well below the quality standard of 0.1 mg/L, but in terms of ‘heavy metal removal efficiency’, its performance is low. In Nov-2024, the efficiency was -8.82% (inefficient). The inlet is slightly lower than the outlet (approximately 0.0034 mg/L \rightarrow 0.0037 mg/L), resulting in negative efficiency. Practically, this difference is very small and still within the range of analytical/laboratory uncertainty. Research by Kumar et al. (2022) also shows that ‘negative removal’ often occurs in WWTP, due to sample fluctuations, analysis variations, or the release of pollutants from sludge back into the water phase. In Dec-2024, the efficiency was 99.69% (Very Efficient). This month, there was a surge in Cd at the inlet (0.48 mg/L) and a decrease to 0.0015 mg/L at the outlet, a reduction of approximately 99.7%. This indicates that when the Cd load is high, the treatment unit is able to remove Cd very effectively, likely through co-precipitation with solids/sludge, adsorption on coagulant flocs or biomass, and binding of Cd in the solid phase.

In Feb, Apr–Sep 2025, efficiency is 0% (inefficient). Most months in 2025 show 0% efficiency because the inlet and outlet concentrations are the same (e.g. 0.02 mg/L → 0.02 mg/L). Similar to 2024, it only ‘passes through’ Cd in the already low range. In Mar-2025, efficiency is -100% (inefficient). The inlet is around 0.01 mg/L and the outlet is 0.02 mg/L, so there is a 100% increase in calculation. The difference is only 0.01 mg/L and is still far below the quality standard. This pattern has been reported (Kumar et al., 2022) in other WWTP for pollutants with very low concentrations, so that even a slight difference is immediately read as negative efficiency.

Research data shows that Cd at the inlet is only 0.0015–0.02 mg/L. At this high concentration, WWTP do not provide significant reduction because Cd is not easily oxidised like COD or ammonia, most of the Cd is bound to solid particles or flocs that have been separated beforehand. A review of leachate treatment confirms that standard biological units are more effective at reducing organic pollutants, while the removal of heavy metals and recalcitrant compounds requires additional processes such as coagulation–flocculation, adsorption, membranes, or other specialised technologies (Sossou et al., 2024). Studies on ‘negative removal efficiency’ indicate that negative efficiency can occur in almost all types of installations due to variations in inlet and outlet sampling times, differences in metal speciation, metal release from sludge, or small analytical errors that become significant in percentage terms at low concentrations. Therefore, the prevalence of ‘inefficient’ labels for Cd does not automatically mean that the WWTP has failed, but rather indicates that Cd has not been a primary target of the treatment process and its concentration was already low from the outset (Kumar et al., 2022).

CONCLUSION

The removal efficiency of WWTP in 2024 is still within a good range, with showing

effective performance with fairly high BOD, COD, TSS, and total nitrogen removal efficiencies. However, the drastic decline that occurred in 2025 indicates that the system has reached saturation, where biological and physical processes are no longer optimal. The decline occurs in almost all leachate treatment parameters, especially BOD and COD, which are the main indicators of leachate treatment quality. It is recommended that routine maintenance and optimisation of the treatment system at the Bongkang landfill be carried out to maintain removal efficiency above 70%. In addition, the application of advanced processes such as Advanced Oxidation Process (AOP), heavy metal adsorption, or membrane filtration should be considered as efforts to improve the performance of the WWTP in the long term.

Declaration by Authors

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