Evaluation of the leachate treatment system from the Terjun Landfill based on toxicity values using goldfish (*Cyprinus carpio* L.) and water fleas (*Daphnia* sp.) as test organisms

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Abstract. The Terjun Landfill employs an open dumping system and receives approximately 1,500 to 2,000 tonnes of waste per day. The Terjun Landfill is surrounded by tidal rivers and traditional fish ponds which could be affected by the existing of the landfill. Leachate as the byproduct of a landfill contains toxic substances that might be a threat to surrounding living organisms. The present study aims to assess the effectiveness of leachate treatment at the Terjun Landfill by comparing the quality of leachate at the influent and effluent stages. The aspects that we analyzed were chemical parameters (pH, BOD, COD, TSS, N-Total, mercury and cadmium levels), LC_{50} values, and toxicity levels. *Cyprinus carpio* and *Daphnia* sp. were selected as test species for leachate qualities. The results show the leachate treatment reduced the concentration of chemical pollutants in the effluent, where BOD and COD showed a significant reduction. However, the total nitrogen (N-total) parameter still does not meet the required quality standards. The LC_{50} value for *Cyprinus carpio* test showed a higher percentage from 4.13 to 6.40% in the effluent stage meaning a decrease in toxicity, as a higher concentration was required to cause mortality. The Toxicity Unit (TUa) values for the influent and effluent were 24.2 and 15.62, respectively, which indicates the leachate quality as the high acute toxicity category. The *Daphnia* sp. test also supported the results demonstrating the influent stage as high acute toxicity by showing LC_{50} of 6.7% and TUa value of 14.8, also indicating high acute toxicity, while the LC_{50} value at the effluent stage was 59.8%, with a TUa value of 1.7. The toxicity test results conclude that the leachate treatment process in the Terjun Landfill has not met the treatment standard to reduce the toxicity level of the leachate, fulfilling the maximum wastewater treatment effluent regulated under the Ministry of Environment and Forestry Regulation. The study found that the leachate treatment output could not be discharged into the environment, as it poses a potential risk of contaminating the aquatic ecosystem and the traditional fish ponds surrounding the Terjun Landfill.
Key Words: acute toxicity, leachate treatment, lethal dose, open dumping, toxicity level.

Introduction. The Terjun Landfill is a waste disposal site located in Medan City. This 14-hectare landfill has been operational since January 7, 1993, and remains active to this day. With a capacity that has reached 1 million cubic meters, the landfill receives waste from 21 districts in Medan City, with an incoming waste volume of 1,500 to 2,000 tonnes per day (Hafizah et al 2023; Safitri et al 2023). The landfill employs an open dumping system, meaning waste is piled up and left exposed without being processed into useful products. The accumulation of waste at the landfill can generate leachate, which has the potential to pollute the surrounding environment if not properly managed (Rahmi & Edison 2019). The highly complex nature of the waste results in leachate with diverse characteristics, including organic and inorganic components, microorganisms, toxic substances, pharmaceuticals, and heavy metals, all of which pose a risk of contaminating groundwater and nearby river systems (Said & Hartaja 2015; Sari & Afdal 2017;

Javanmardi et al 2022). Currently, a new landfill has been constructed in Medan City using the sanitary landfill method on the remaining 4-hectare area of the Terjun Landfill, where waste will be periodically covered with soil. It is estimated that this new landfill will only have the capacity to handle waste for four years, based on the available land area and the volume of incoming waste (Hafizah et al 2023).

Leachate is formed from the accumulation and decomposition of waste piles beneath the landfill. Its composition, which includes organic and inorganic materials, heavy metals, and xenobiotic substances, can contaminate groundwater and surface water, leading to the death of aquatic organisms. Generally, the production of leachate in landfills begins with rainwater washing over the landfill surface, entering drainage systems, and subsequently infiltrating surface and groundwater in the surrounding area (Wang & Qiao 2024). During rainfall, water percolates through the waste piles, carrying high concentrations of harmful substances that overflow or seep out of the waste (Kusumawati 2012). Groundwater contamination is a serious consequence of the open dumping method used at the landfill. This system allows waste to be piled up daily without undergoing any treatment. The continuous accumulation of waste leads to decomposition processes that produce toxic gases and leachate, which can contaminate groundwater (Meilasari et al 2021). The impact of such pollution not only damages the environment but also increases health risks for communities living near the landfill. Seepage from the waste piles can contaminate groundwater sources used by nearby residents for drinking and other daily needs (Kumari et al 2017). Research conducted by Ashar et al (2014) revealed cadmium contamination in river water and shrimp ponds near the Terjun Landfill, indicating that leachate seepage potentially carries xenobiotic substances and heavy metals, contaminating water sources and posing health risks to the community. Soil and groundwater pollution from leachate also disrupts biodiversity, nutrient cycles, and the survival of organisms in the ecosystem (Thomas & Santoso 2019; Fadhila & Purwanti 2022; Syuzita et al 2022).

The current condition of the Terjun Landfill shows that there are two main ponds used to collect leachate from the drainage system. These ponds are suspected to function as stabilization treatment units, consisting of a facultative pond and a maturation pond. After undergoing treatment in the maturation pond, the leachate is directed to an outlet control tank before being discharged into the environment. However, the discharge of leachate from the outlet occurs through direct seepage into the soil, posing a risk of contaminating the soil and groundwater in the landfill vicinity. Research by Novianti (2018) found that the mercury content in the leachate at the Terjun Landfill ranged from 0.09 mg L^{-1} at the inlet to 0.05 mg L^{-1} at the outlet, while cadmium levels were below 0.003 mg L^{-1} at both the inlet and outlet. The presence of these metals can exacerbate pollution impacts if the leachate treatment system does not comply with environmental quality standards (Kartikasari et al 2020). Regulations regarding leachate quality standards are outlined in the Indonesian Ministry of Environment and Forestry Regulation No. 59 of 2016, which sets the permissible limits for leachate parameters such as pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total nitrogen (N-total), mercury, and cadmium before discharge into the environment.

To date, no studies have assessed the effectiveness of leachate treatment at the Terjun Landfill, making this research crucial for evaluating the quality of the leachate produced and its potential environmental impact, particularly through toxicity testing. Toxicity testing measures the ability of a toxic substance (molecule) to cause harm when it enters the body and affects vulnerable organs. It is a representative method for estimating the hazards posed by leachate (Soemirat 2003). Toxicity testing provides an overview of the effects of a substance on selected organisms. It typically measures the proportion of organisms affected by exposure to specific concentrations of a chemical, waste, leachate, or receiving water (Haz 2018). Toxicity testing can serve as a basis for assessing the impact of wastewater discharge on the environment, as it directly affects organisms in the ecosystem.

In this study, the effectiveness of leachate treatment at the Terjun Landfill was evaluated through leachate toxicity testing. The toxicity tests involve *Cyprinus carpio* and

Daphnia sp. as sample organisms affected by leachate discharge. The treatment effectiveness was measured by determining the minimum concentration threshold of leachate exposure that affects the test organisms (Ratningsih 2008), exhibit reactions to changes in water quality and the presence of dissolved pollutants at certain concentrations (Grazella 2018), while *Daphnia* sp. are sensitive organisms for analysing the toxicology of complex mixtures found in landfill leachate (Restrepo et al 2017; Przydatek 2019; Wdowczyk & Szymańska-Pulikowska 2021). The results of leachate treatment effectiveness testing provide critical information for landfill management because Terjun landfill is surrounded by tidal rivers and traditional ponds for aquaculture. Beside that, this is particularly important as residential areas located near the landfill rely on well water for daily needs, which is at risk of contamination from leachate-polluted groundwater.

Material and Method

Description of the study sites. The leachate samples used in this study were collected from the Terjun Landfill, located in Paya Pasir, Medan Marelan District, Medan City. For the leachate treatment in the Terjun Landfill, there is no official information available regarding the type of leachate treatment process implemented. However, the existing conditions indicate the presence of two main ponds used to collect leachate from the drainage system which presumed as stabilization treatment units, consisting of a facultative pond and a maturation pond. The leachate from the maturation pond is then channeled to an outlet control tank before being discharged into the environment. The samples used in the present study were the influent leachate sourced from the drainage system before entering the treatment tank, and the effluent leachate which obtained from the outlet tank as the treated leachate output. Leachate sampling was conducted during the dry season of 2024, spanning from March to May, following the guidelines outlined in SNI 6989.59:2008. The map illustrating the leachate sampling locations is depicted in Figure 1.

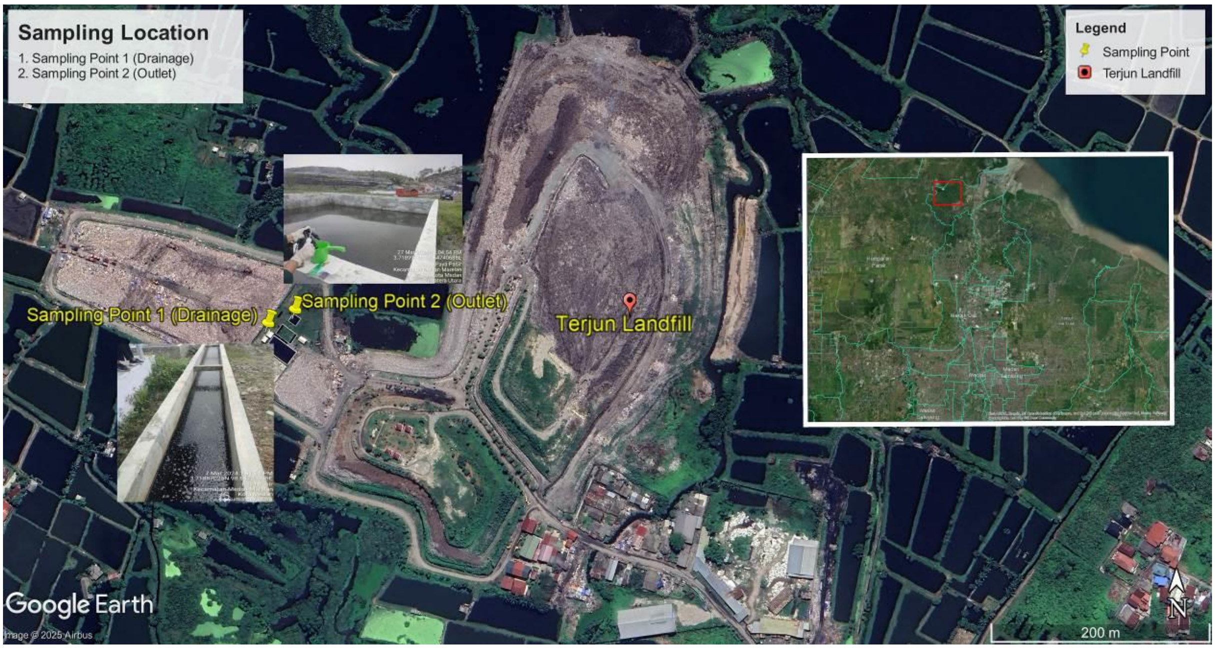


Figure 1. The location of sampling points at Terjun Landfill, Medan, Indonesia.

Leachate characterization. The leachate obtained from the influent and effluent was tested for quality using several parameters, including pH, TSS, BOD, COD, N-total, mercury (Hg), and cadmium (Cd). The pH measurement was conducted in situ at the sampling point, while the other parameters were analyzed in the laboratory. The pH testing method adhered to Indonesian National Standard (abbreviated as Standard Nasional Indonesia or SNI) Number 6989.59:2008; BOD testing followed SNI Number 06-

6989.72:2009; TSS testing followed National Standard Indonesia Number 06-6989.3:2019; N-total testing followed APHA (2012); COD, mercury, and cadmium were analyzed using atomic absorption spectrophotometry analysis.

***Acute biotoxicity test**.* The acclimatization process was conducted as an initial step to prepare for the preliminary and definitive tests. The acclimatization of *Cyprinus carpio* was carried out using 95 liters of drinking water over 96 hours for 264 fishes in an aquarium with a specific dimension of 90 cm (length) × 40 cm (width) × 40 cm (height). The acclimatization of water fleas (*Daphnia* sp.) was performed using 6.6 liters of drinking water over 24 hours for 660 *Daphnia* sp. in an aquarium with a specific dimension of 30 cm (length) × 30 cm (width) × 30 cm (height). The mortality count of the test organisms, as well as measurements of temperature, dissolved oxygen (DO), and pH, were recorded at 3, 6, 24, 48, and 96 hours of leachate post-exposure. The acclimatization process was conducted in four stages: stage I stands for the preliminary test of drainage leachate, stage II is for the definitive test of drainage leachate, stage III is for the preliminary test of outlet leachate, and stage IV is for the definitive test of outlet leachate.

The preliminary test was conducted to determine the upper and lower threshold concentrations to be used in the definitive test. The leachate concentration variations (%) in the preliminary test, for both *C. carpio* and *Daphnia* sp. were 0% (control), 6.25%, 12.5%, 25%, 50%, and 100%. The preliminary test was repeated twice for each test organism. The preliminary test for *C. carpio* utilized a reactor in the form of an aquarium with a specific dimension of 30 cm (length) × 30 cm (width) × 30 cm (height), containing 20 individuals of *C. carpio* with a total water of 10 liters. The preliminary test for *Daphnia* sp. was conducted in glass jars containing 50 individuals of *Daphnia* sp. with a 500 mL of water.

The definitive test was conducted as a follow-up to determine the LC_{50} value. This test involved a control and five new concentration variations of the leachate solution, based on the upper and lower threshold concentrations derived from the preliminary test. The new concentrations for the definitive test were determined using a logarithmic series with the following equations:

$$\log\left(\frac{N}{n}\right) = k\left(\log\frac{a}{n}\right) \quad (1)$$

$$\frac{a}{n} = \frac{b}{a} = \frac{c}{b} = \frac{d}{c} = \frac{e}{d} \quad (2)$$

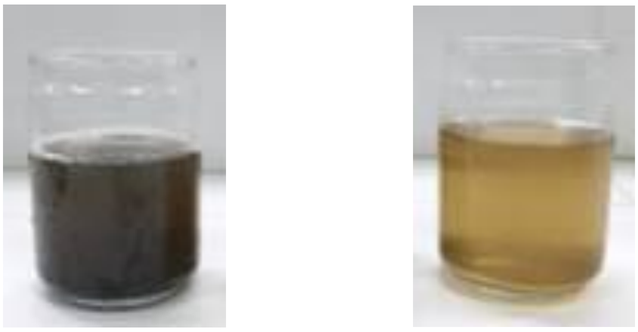
where: N represents the upper threshold concentration; n denotes the lower threshold concentration; k is the number of concentration intervals tested; a is the smallest concentration in the new series (Variation I); b is the second concentration in the new series (Variation II); c is the third concentration in the new series (Variation III); d is the fourth concentration in the new series (Variation IV); and e is the fifth concentration in the new series (Variation V). The definitive test was conducted using the same reactors as the preliminary test, with the same number of test organisms and water volume as in the preliminary test.

***Probit analysis method and toxicity unit acute calculation**.* The mortality of test organisms was measured using the LC_{50} value, which represents the concentration capable of causing 50% mortality in the test organisms within a specified period. This study employed the probit analysis method, a nonparametric statistical procedure used to determine the LC_{50} (USEPA 2002). The LC_{50} value is derived from the linear regression equation generated from the graph depicting the relationship between the log concentration and the probit value. The basic formula is linier regression, where the value of Y is the probit value, obtained by transforming the mortality percentage using the Finney probit transformation table; a is the linear regression coefficient "a"; b is the linear regression coefficient "b", x is the log concentration.

After obtaining the LC_{50} value, the TUa (Toxicity Unit Acute) was calculated to determine the acute toxicity level of the landfill leachate. The toxicity level categories based on the TUa value are as follows: no acute toxicity (TUa < 0.4), mild acute toxicity

(0.4 < TUa < 1), acute toxicity (1 < TUa < 10), high acute toxicity (10 < TUa < 100), and very high acute toxicity (TUa > 100) (Restrepo et al 2017; Przydatek 2019). The TUa value was calculated with dividing 100% to LC_{50} in percentage.

Results and Discussion. The quality of leachate water at the Terjun Landfill was determined by the physicochemical parameters of the leachate, as regulated under the Ministry of Environment and Forestry Regulation No. 59 of 2016 concerning the quality standards for leachate in waste processing and/or final disposal sites. Physically, the leachate samples taken from the influent are dark brown in color and emit a pungent odor compared to the treated leachate at the outlet indicating high organic contents in the sample as shown in the Figure 2. The presence of organic, inorganic, and heavy metal constituents in the leachate renders high toxic compounds to the test organisms (Sackey et al 2020). The laboratory test results show that most physicochemical parameters in the drainage leachate exceed the established quality standards, such as BOD, COD, and TSS (Table 1). The presence of organic, inorganic, and heavy metal components in the leachate has the potential to make it toxic to test animals (Carabalí-Rivera et al 2017). Table 1 showed the results of the leachate water quality testing for chemical parameters.



(a) (b)

Figure 2. (a) influent leachate; (b) effluent leachate.

Table 1

Leachete quality of Terjun Landfill

Parameter	*Unit*	*Indonesian standard**	*Test result*	
			Influent	*Effluent*
pH	-	6-9	7.22	8.17
BOD	mg L^{-1}	150	1137	49.5
COD	mg L^{-1}	300	3750	97.85
TSS	mg L^{-1}	100	106	32
N-total	mg L^{-1}	60	15.98	143.35
Mercury (Hg)	mg L^{-1}	0.005	0.000109	0.0005
Cadmium (Cd)	mg L^{-1}	0.1	0.040	0.031

*) Ministry of Environment and Forestry Regulation No. 59 of 2016 concerning the Quality Standards for Leachate.

The results of leachate quality testing at the outlet demonstrate a percentage reduction in BOD, COD, and TSS of 96%, 97%, and 70%, respectively. The leachate treatment process at the Terjun Landfill is effective in reducing pollutant levels, particularly the chemical parameters in the leachate, to meet the quality standards established under the Ministry of Environment and Forestry Regulation No. 59 of 2016 concerning the Quality Standards for Leachate in Waste Processing and/or Final Disposal Sites.

Acute biotoxicity result. *C. carpio* used for the testing were healthy individuals measuring 3-5 cm in length. During the acclimatization period, *C. carpio* were fed commercial fish food twice daily at 09:00 and 15:00 for three days. Twenty-four hours prior to the testing, feeding was discontinued (Jasansong et al 2020). Throughout the acclimatization process, oxygen was supplied using an aerator. For the *Daphnia* sp., the selected sample for the testing were young neonates, approximately 1 mm in size, and in healthy condition (actively swimming). At the end of the acclimatization period, the young *Daphnia* sp. were fed two hours before proceeding to the preliminary and toxicity tests. Table 2 shows the acclimatization result for *Daphia* sp. and *C. carpio.*

Table 2

Acclimatization result for 96 hours

Parameter	*Unit*	*Species*	
		Daphia sp.	*Cyprinus carpio*
Population	Individuals	660	264
Mortality rate	%	0	6±1
Temperature	°C	28.89±0.4	28.4±0.5
DO	mg L^{-1}	7.49±0.5	7.3±0.5
pH	-	7.28±0.5	7.2±0.3

Based on the test results, the average values of pH, temperature, and DO during the acclimatization process were still within the optimal range for the survival of *C. carpio*. Based on Indonesian National Standard/SNI 8296.4 (2016), the optimal water temperature for *C. carpio* is 25-30°C, the pH range is 6.5-8.5, and the minimum DO content is 5 mg L^{-1}. The acclimatization process in both stages did not show significant differences, as the same treatment was applied. The water temperature during acclimatization ranged between 27 and 29°C, DO levels ranged between 7 and 8 mg L^{-1}, and pH levels ranged between 6 and 8. In a similar study conducted by Kartikasari et al (2020), *Daphnia* sp. were able to thrive at a temperature of 27°C, a pH range of 8.2-8.5, and a DO level of 3 mg L^{-1}. According to USEPA (2002), the optimal environmental conditions for *Daphnia* sp. are a pH range of 6-9, DO ≥ 3 mg L^{-1}, and a temperature of 25±1°C (recommended).

In this study, the temperature was not within the optimal range as recommended, as the research was conducted during the dry season in Medan City. However, Effendi (2003) stated that temperatures within the range of 20-30°C are suitable for the survival of phytoplankton. The quality of life for *Daphnia* sp. is influenced by their environment. Under normal conditions, *Daphnia* sp. can grow well, but under extreme conditions, they can adapt by producing hemoglobin in their hemolymph to aid in oxygen distribution within their bodies (Pattiwael et al 2013). Nevertheless, extreme conditions can lead to changes in the reproductive system of *Daphnia* sp. (Stollewerk 2010)0. In this study, the environmental quality, measured based on temperature, DO, and pH parameters, remained within safe limits to support the survival of *Daphnia* sp.

During the acclimatization stage, a small number of *C. carpio* mortalities occurred, whereas no mortalities were observed in *Daphnia* sp. Mortality during acclimatization may be attributed to the inability of some organisms to adapt to the new environment, resulting in stress. According to USEPA (2002), acclimatization is considered successful if the mortality rate is ≤ 10%. In this study, the mortality rate of the test organisms in each trial was ≤ 10%. Therefore, the acclimatization process was successful, and the dilution water was deemed suitable for toxicity testing.

This test was conducted using leachate collected from the drainage system of the Terjun Landfill, representing the inlet source, and leachate obtained from the final pond before being discharged into the water body, representing the outlet. Visually, the leachate from the inlet appeared black, while the leachate from the outlet was dark brown. The difference in color is influenced by the presence of high organic matter content.

Exposure to leachate at varying concentrations resulted in different mortality effects on *C. carpio* and *Daphnia* sp.. Higher concentrations of leachate tended to kill *C. carpio* and *Daphnia* sp. within a short period. At the initial stage of leachate exposure, behavioral changes were observed in both *C. carpio* and *Daphnia* sp. Prior to mortality, *C.*

carpio exhibited behavioral changes, including hyperactive movements, loss of balance, a tendency to gather at the water surface, difficulty breathing, excessive mucus production, and fading of body color. Meanwhile, leachate exposure in *Daphnia* sp. caused hyperactive movements that gradually slowed over time, eventually leading them to swim to the bottom of the reactor. *Daphnia* sp. were considered dead if they showed no movement response after the sample was shaken for 15 seconds (Wahyuningsih et al 2020; Wdowczyk & Szymańska-Pulikowska 2021). Similar to *C. carpio*, at the point of death, *Daphnia* sp. exhibited physical damage to their bodies (Anggraini et al 2019). The mortality rates of *C. carpio* and *Daphnia* sp. at varying leachate concentrations are shown in Figure 3.

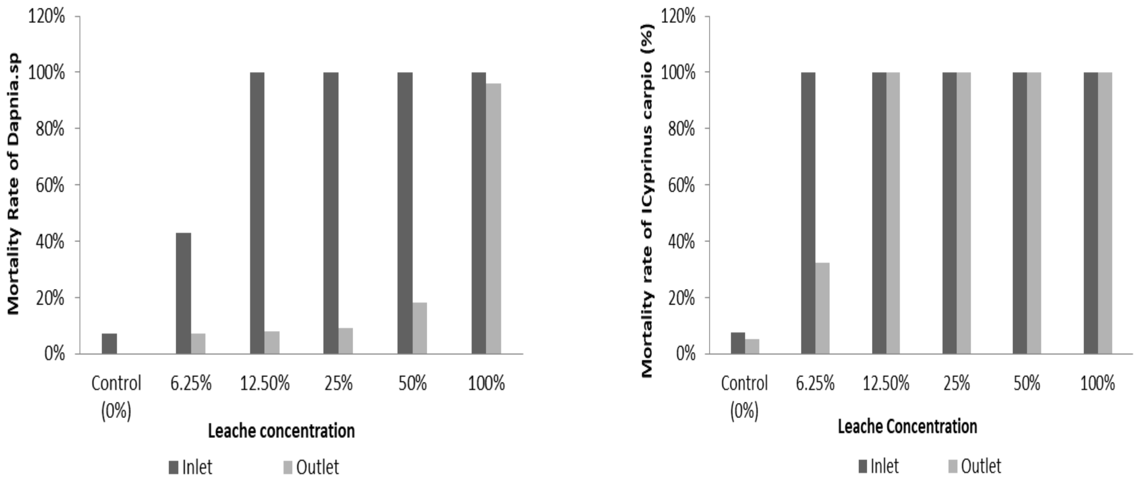


Figure 3. Mortality rate in preliminary test result for *Daphnia* sp. and *Cyprinus carpio*.

The highest mortality rate for *Daphnia* sp. occurred at leachate concentrations sourced from the inlet. The mortality percentage data indicated a significant reduction in *Daphnia* sp. mortality after the leachate was treated. A significant decrease in mortality was observed for *Daphnia* sp. at concentrations of 6.25%, 12.5%, 25%, and 50%. Meanwhile, in the tests involving *C. carpio*, a reduction in mortality percentage only occurred at a concentration of 6.25%. Both inlet and outlet leachate at concentrations of 12.5% and above were highly toxic to *C. carpio*, resulting in the complete elimination of the *C. carpio* population.

Based on the test results, *C. carpio* were more susceptible to mortality compared to *Daphnia* sp., even at the same concentrations. Generally, *Daphnia* sp. are considered more sensitive than other organisms (Lee et al 2016; Restrepo et al 2017). However, the sensitivity of test organisms to toxicity is also influenced by their specific responses to the pollutants present in the test samples, which can result in varying effects on different test species. In this study, the leachate parameters tested were limited to those regulated by applicable standards, while leachate contains a variety of toxic compounds with differing sensitivities when exposed to *Daphnia* sp. and *C. carpio*. Fish are more sensitive to dieldrin, lindane, and pentachlorophenol, while *Daphnia* sp. are highly sensitive to aniline, heavy metals, malathion, and parathion (ECETOC 2003). Additionally, ammonia may also contribute to the susceptibility of *C. carpio* in toxicity tests. The excretory system of *C. carpio* produces ammonia, which is released into the water through urine and gills (Ip & Chew 2010). The static testing method (without solution replacement) can lead to elevated ammonia concentrations in the aquarium, potentially causing oxidative stress and physiological damage to the fish (Guo et al 2022). At the end of the tests at high leachate concentrations, it was observed that the bodies of *C. carpio* darkened, which may indicate the effects of ammonia exposure in the water (Fernandes & Mazon 2003).

In toxicity testing, parameters such as temperature, DO, and pH must be controlled to maintain environmental conditions suitable for the survival of *Daphnia* sp. Temperature fluctuations can affect the comfort of *Daphnia* sp. in the test reactor.

Overall, the average temperature during the preliminary tests did not exceed 30°C, the average DO levels were ≥ 3 mg L^{-1}, and the average pH ranged between 6 and 9, which means the conditions remained within the optimal range for the survival of both *C. carpio* and *Daphnia* sp. (USEPA 2002). Proper environmental conditions are necessary to ensure that the mortality of test organisms is solely due to leachate exposure. This is supported by the observation that mortality in the control reactors was < 10% of the population at the end of each test, confirming that the toxicity data are valid and can proceed to definitive testing. The results of the preliminary tests on *C. carpio* and *Daphnia* sp. are shown in Table 3.

Table 3

Concentration thresholds of leachate

Sampling location	*Biota test*	*Leachate concentration (%)*	
		Lower limit	*Upper limit*
Inlet	*Cyprinus carpio*	0	6.25
	Daphnia sp.	6.25	12.5
Outlet	*Cyprinus carpio*	6.25	12.5
	Daphnia sp.	50	100

The definitive test was conducted over a period of 96 hours to determine the LC_{50} value. In the definitive test, the variation in leachate concentration used was based on the results obtained from the preliminary test, which were subsequently processed using a logarithmic formula. For *C. carpio* test, the leachate concentration variations for the inlet were 1.4%, 2.1%, 3.0%, 4.3%, and 6.25%, while for *Daphnia* sp., the concentrations were 0%, 7.2%, 8.2%, 9.5%, 10.9%, and 12.5%. For the outlet leachate, the concentration variations used in *C. carpio* test were 7.2%, 8.2%, 9.5%, 10.9%, and 12.5%, whereas for *Daphnia* sp., the concentrations were 0%, 57.4%, 66%, 75.8%, 87.1%, and 100%. The results of the definitive test indicated that the mortality rate of the test organisms varied according to the leachate water concentration used. The percentage mortality of the test organisms at different leachate water concentrations, sourced from both the inlet and outlet, are shown in Figure 4.

The mortality rate exhibits a direct correlation with leachate concentration, wherein higher concentrations result in an increased percentage of organism mortality. Leachate from the inlet demonstrated a rise in mortality within the *Daphnia* sp. population, reaching 98% mortality at a concentration of 12.5%. In contrast, mortality in *C. carpio* began to increase at concentrations of 3% and above, reaching 100% at a concentration of 6.25%, indicating high toxicity. Meanwhile, mortality induced by exposure to outlet leachate in *Daphnia* sp. started to increase at concentrations of 66% and above, whereas mortality in *C. carpio* was already elevated at a concentration of 7.2% and continued to rise, reaching 100% at concentrations ranging from 9.5 to 12.5%.

In this test, the *C. carpio* population experienced higher mortality compared to *Daphnia* sp. *C. carpio* exposed to inlet leachate at a concentration of 6.25% exhibited 100% mortality, while *Daphnia* sp. survived until the end of the test at a concentration of 12.5%. This difference may be attributed to the varying sensitivity of *C. carpio* and *Daphnia* sp. to the leachate. Throughout the test, the average values of pH, temperature, and DO were maintained to support the survival of both *C. carpio* and *Daphnia* sp., thereby minimizing mortality due to these parameters. Additionally, mortality in the control reactor for both *C. carpio* and *Daphnia* sp. was ≤ 2%, ensuring that the data remained acceptable (USEPA 2002).

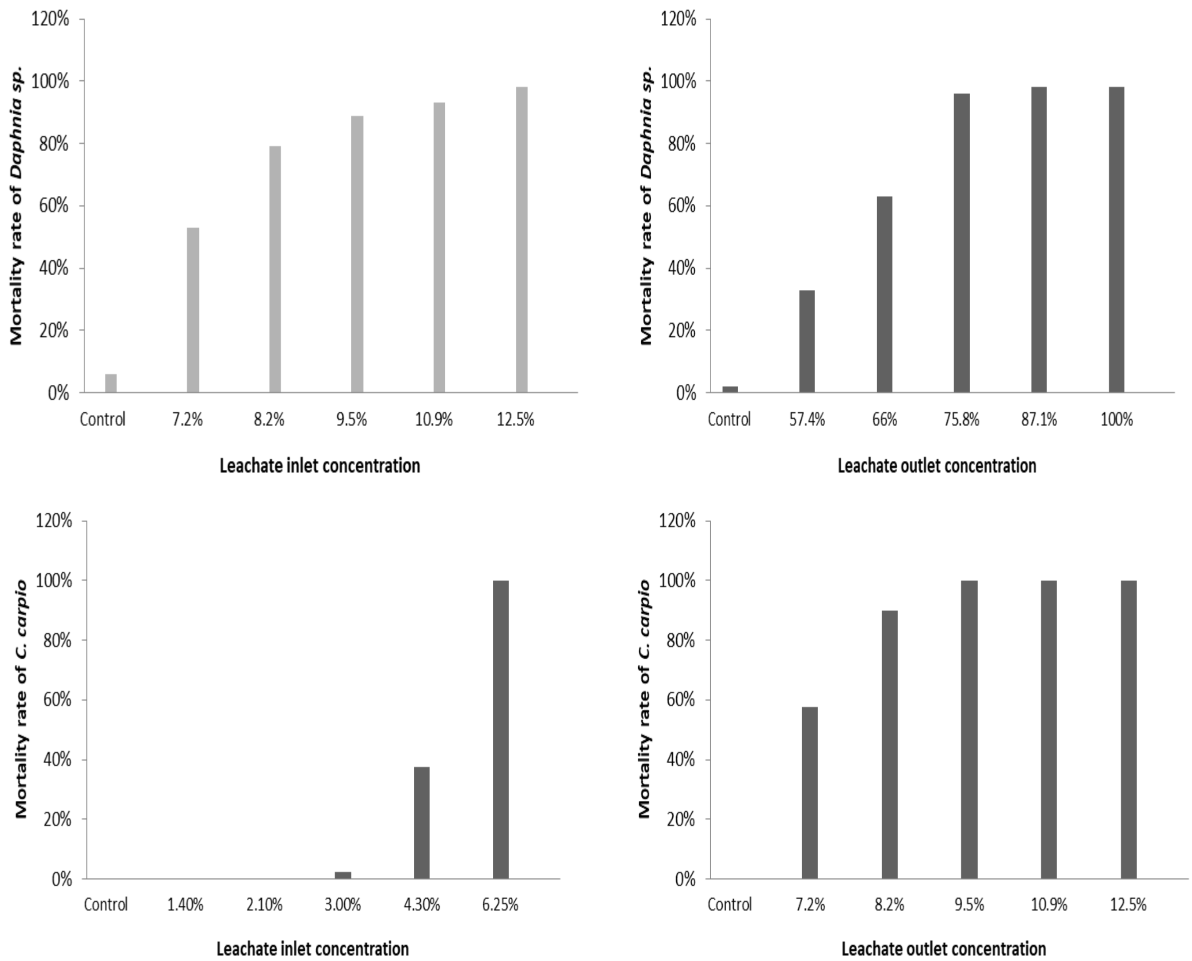


Figure 4. Mortality rate in definitive test result.

LC_{50} and toxicity unit acute result. The LC_{50} value of the leachate was determined as the concentration that caused 50% mortality in the test organisms when exposed to the leachate for 96 hours. The method used to calculate the LC_{50} value was the probit method. The results of the LC_{50} calculations for *C. carpio* and *Daphnia* sp. are presented in Table 4.

Table 4

Toxicity test results

Sampling point	*Biota test*	*Regression equation*	*a value*	*b value*	*LC_{50}*	*TUa*
Inlet	*C. carpio*	y = 15.619x-35.862	15.619	-35.862	4.13%	24.2
	Daphnia sp.	y = 7.6332x – 16.591	7.6332	-16.591	6.7%	14.8
Outlet	*C. carpio*	y = 12.619x-30.412	12.619	-30.863	6.4%	15.62
	Daphnia sp.	y = 11.121x – 36.999	11.121	-36.999	59.8%	1.7

The test results on the test organisms indicated that the inlet leachate exhibited high acute toxicity levels toward both organisms, while the outlet leachate demonstrated higher toxicity toward *C. carpio* compared to *Daphnia* sp. The LC_{50} value is inversely proportional to the TUa, where a lower LC_{50} value indicates higher toxicity of the leachate. Conversely, a higher TUa value reflects more acute toxicity. Based on the test results, the TUa values for the inlet leachate for both organisms, as well as the TUa values for the outlet leachate toward *C. carpio*, fall under the category of high acute toxicity. This indicates that the leachate can cause lethal effects even at very low exposure levels.

Several parameters, such as pH, BOD, COD, and TSS in the outlet leachate, have met the quality standards set by the Indonesian Ministry of Environment and Forestry Regulation No. 59 of 2016. However, exposure to the leachate still demonstrated toxic effects on the organisms. According to Kjeldsen et al (2002), leachate contains dissolved organic matter, inorganic macrocomponents, heavy metals, and xenobiotic organic compounds that are highly hazardous to the environment. Therefore, these parameters need to be further investigated due to their significant adverse impacts. The results of this testing provide critical input for the evaluation and formulation of regulations. Many parameters currently regulated by ministerial guidelines are not sufficiently representative in describing the toxicity of leachate to the environment.

From the conducted research, landfills with similar characteristics exhibit comparable toxicity levels, as seen in the study by Maulidia et al (2023) which assessed the toxicity of leachate from the Batu Layang landfill toward tilapia. The toxicity level at this landfill was categorized as high acute toxicity, with a TUa value of 44.24% and an LC_{50} value of 2.26%. A similar trend was observed at the Muara Fajar landfill, where *C. carpio* were used as test organisms. The TUa value for the leachate from Muara Fajar was 27.81, classified as high acute toxicity, with an LC_{50} value of 3.595% (Faradisha et al 2015). Likewise, in the study by Grazella (2018) at the Piyungan landfill, which also used *C. carpio* as test organisms, the LC_{50} value for influent leachate ranged at 1.633%, with a TUa value of 61.23, categorized as high acute toxicity. For effluent leachate, the LC_{50} value was 8.740%, with a TUa value of 11.44, classified as a high toxicity level.

Similar findings were observed in studies assessing landfill toxicity toward *Daphnia* sp. For instance, in the study by Kartikasari et al (2020) which evaluated the toxicity of leachate from the Piyungan landfill toward *Daphnia* sp., the landfill exhibited very high toxicity levels, with an LC_{50} of 0.482% and a TUa of 203.33 (influent), as well as an LC_{50} of 2.752% and a TUa of 36.33 (effluent), indicating higher toxicity compared to the Terjun landfill. The Panevėžys landfill in Lithuania, as studied by Žaltauskaitė & Vaitonytė (2016) had an LC_{50} for *Daphnia* sp. of 6.92% and a TUa of 14.45, which is very similar to the drainage values of the Terjun Landfill, suggesting comparable toxicity levels. The Regional Landfill in Colombia, as studied by Carabalí-Rivera et al (2017) showed an LC_{50} for *Daphnia* sp. of 2.02% and a TUa of 49.5, indicating higher toxicity than the Terjun Landfill. Thus, the Terjun Landfill exhibits lower toxicity levels compared to several other landfills, particularly in the outlet section. However, it still demonstrates potential toxicity, highlighting the need for improved treatment efficiency and further investigation into other toxic parameters present in the leachate.

Conclusions. The 96-hour LC_{50} values of the leachate from the drainage of the Terjun Landfill for *Cyprinus carpio* and *Daphnia* sp. were 4.13% and 6.7%, respectively, with TUa values of 24.2 and 14.8, which fall under the category of high acute toxicity. Meanwhile, the 96-hour LC_{50} values of the outlet leachate from the Terjun Landfill for *Cyprinus carpio* and *Daphnia* sp. were 6.4% and 59.8%, respectively. The TUa value of the outlet leachate for *Cyprinus carpio* was 15.62, classified as high acute toxicity, while the TUa value of the outlet leachate for *Daphnia* sp. was 1.7, categorized as acute toxicity. Although the treatment of leachate at the Terjun Landfill has met the quality standards for leachate as per government regulations, it has not been able to reduce the toxicity level of the leachate. As a result, the discharge of effluent into water bodies has the potential to impact the aquatic ecosystem surrounding the Terjun landfill. This study also highlights that the water quality parameters regulated in current legislation do not adequately represent the toxic nature of landfill leachate.

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Conflict of interest. The authors declare that there is no conflict of interest.

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