Impact of Leachate Discharge from Cipayung Landfill on Water Quality of Pesanggrahan River, Indonesia

Eki Noerfitriyani¹, Djoko M. Hartono, Setyo S. Moersidik, Irma Gusniani

¹ Environmental Engineering Study Program, Civil of Engineering Department, Universitas Indonesia, Depok, West Java, 16424, Indonesia
E-mail: eki.noerfitriyani@ui.ac.id

Abstract. The landfill operation can cause environmental problems due to solid waste decomposition in the form of leachate. The evaluation of environmental impacts related with solid waste landfilling is needed to ensure that leachate discharge to water bodies does not exceed the standard limit to prevent contamination of the environment. This study aims to analyze the impact of leachate discharge from Cipayung Landfill on water quality of Pesanggrahan River. The data were analyzed based on leachate samples taken from influent and effluent treatment unit, and river water samples taken from upstream, stream at leachate discharge, and downstream. All samples were taken three times under rainy season condition from April to May 2017. The results show the average leachate quality temperature is 34.81 °C, TSS 72.33 mg/L, pH 7.83, BOD 3,959.63 mg/L, COD 6,860 mg/L, TN 373.33 mg/L, Hg 0.0016 mg/L. The BOD₅/COD ratio 0.58 indicated that leachate characteristics was biodegradable and resemble intermediate landfill due to the mixing of young leachate and old leachate. The effluent of leachate treatment plant exceeds the leachate standard limit for BOD, COD, and TN parameters. Statistical results from independent T-test showed significant differences (p<0,05) between upstream and downstream influenced with leachate discharge for DO parameter.

1. Introduction

The population growth in urban areas leads to the high volume of solid waste generated. Inevitably, this development has a significant impact on the increasing amount of solid waste disposed at Cipayung Landfill, Depok City. Depok City had the population over 2 million persons [1]. It generates solid waste 1,200 tonnes/day mainly derived from households, and solid waste disposed to Cipayung Landfill reached 750 tonnes/day [2]. Cipayung Landfill has been operated since 1984 using a controlled landfill system [2]. The increasing amount of waste generation can cause problems in its operation. Moreover, an improper waste management is potentially harmful to human health and can lead to environmental degradation. One potential environmental issue driven by the decomposition of waste in landfills is leachate production. Leachate can be derived from rain water seepage, runoff of waste decomposition, and moisture content of the waste itself [3]. The characteristics of leachate produced depend on several factors, including the degree of stabilization of the dumped waste, solid waste collection system, the type and composition of the discarded waste [4], the solubility of solid waste content [5], site and hydrological factors, solid waste compaction, as well as landfill design and operations [6]. Leachate is a liquid manifestation of solid waste and has been considered a serious polluter that affects natural resources such as water bodies and groundwater, as well as human health. Leachate is a contaminated liquid derived from the bottom of solid waste disposal facilities such as landfills containing dissolved organic compounds and inorganic compounds and suspended solids. The leachate composition depends on the nature of solid waste, chemical, and biochemical processes for...
the decomposition of waste materials, as well as the total moisture content of solid waste [7]. Cipayung Landfill has a leachate treatment plant for treating leachate from landfill using a stabilizing pond treatment system. Stabilization ponds are large basins in which wastewater is treated by natural processes involving microorganisms, and are considered as the most appropriate method for wastewater treatment in developing countries where the climate is favorable for its operation [8]. Stabilization pond system can be classified based on the types of biological activity, i.e. anaerobic, facultative, and maturation ponds [9]. Treated leachate is then discharged to the Pesanggrahan River. In Indonesia, the quality standards for liquid waste disposal are stated in Indonesia’s Ministry of Environment and Forestry Law No. 59 of 2016 to ensure that the disposal of waste to recipient water bodies will not cause damage to the aquatic ecosystem and its potential economic resources, as well as public health affairs. Of the several contaminants carried in leachate, organic matter, nitrogen, and heavy metals are the primary substances of concern. In general, the concentration of the substances contained in the leachate depends on the biochemical decomposition of solid waste in landfills [10]. The main objectives of this study are to analyze leachate characterization, evaluate the performance of leachate treatment plant, and analyze impact of leachate discharge from Cipayung Landfill site on water quality of Pesanggrahan River, Indonesia. The results of leachate characterization of Cipayung Landfill treatment plant is expected to be useful for landfill management, especially to improve the existing leachate treatment system and prevent contamination of discharged leachate to recipient water bodies.

2. Method

2.1. Description of study area

This study was conducted in Cipayung Landfill, located in Depok, Indonesia. The climate in Depok City is influenced by monsoon season and is relatively similar, characterized by fairly small rain differences. The conditions of rainfall in all Depok areas are practically the same, with the average rainfall of 3,332 mm/year or 278 mm/month and the mean temperature of 26°C [11]. The leachate treatment system applied in Cipayung Landfill is a stabilization pond system. Figure 1 shows that the Cipayung Landfill stabilization pond consists of an anaerobic pond (AP), facultative pond (FP), and maturation pond (MP). The leachate treatment plant has a pretreatment unit equalization tank that is followed by the stabilization pond system. The treated leachate of the treatment plant is discharged to Pesanggrahan River as recipient water body. Pesanggrahan River is classified as Class III water body [12], based on Government Regulation No. 82 of 2001 is a group of water bodies with designated for fisheries and livestock activity.

![Figure 1. Schematic flow diagram of leachate treatment plant Cipayung Landfill.](image)

2.2. Data collection and analysis

In this study, leachate samples were taken every two weeks under rainy season condition from April to Mei 2017. Table 1 describes the sampling locations and shows that samples were taken from leachate treatment plant and from Pesanggrahan River. Leachate samples were collected from inlet and outlet each treatment units to analyzed their characteristics and evaluated the performance of leachate treatment plant. River water samples were collected from upstream before leachate discharge, stream at leachate discharge, and downstream after leachate discharge to analyze the impact of leachate discharge from Cipayung Landfill on water quality of Pesanggrahan River. The sampling procedure follows SNI (Indonesian National Standard) number 6989.59:2008 which explains the wastewater sampling method, and SNI number 03.7016:2004 explains the river water sampling method. Impact of leachate discharge on river water quality were analyzed based on temperature (T), Total Suspended
Solids (TSS), (pH) value, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Total Nitrogen (TN), and Mercury (Hg) parameters. Sampling analysis including in-situ and ex-situ measurement. The temperature is measured using a digital thermometer (SNI 6989.23:2005), TSS using gravimetric analysis (SNI 6989.3:2004), pH value using a digital pH meter (SNI 06-6989.11-2004), BOD$_3$ using Winkler with 5 days incubation time (SNI 6989.72.2009), COD using the close reflux titrimetric method (SNI 06-6989.2-2009), TN using spectrophotometer with Nessler (HACH 399), and Mercury using Atomic Absorption Spectrophotometry method (SNI 6989.78:2011). The methodology developed to study the impact of leachate discharge from Cipayung Landfill on water quality of Pesanggrahan River is divided into several steps, that is identification and characterization of leachate influent, performance evaluation based on removal efficiency, and identification of river water quality influenced with leachate discharge.

### Table 1. Leachate and river water sampling locations.

| Sampling point | Sampling location                             | Latitude; Longitude                  |
|----------------|---------------------------------------------|-------------------------------------|
| S1             | Anaerobic pond influent                     | 6°25'11.60"S; 106°47'14.42"E        |
| S2             | Anaerobic pond effluent; Facultative pond influent | 6°25'11.78"S; 106°47'13.70"E        |
| S3             | Facultative pond effluent; Maturation pond influent | 6°25'12.09"S; 106°47'14.15"E        |
| S4             | Maturation pond effluent                    | 6°25'11.94"S; 106°47'13.55"E        |
| S5             | Upstream of leachate confluence with Pesanggrahan River | 6°25'32.20"S 106°47'20.00"E         |
| S6             | Leachate confluence with Pesanggrahan River | 6°25'11.77"S 6°25'11.77"E           |
| S7             | Downstream of leachate confluence with Pesanggrahan River | 6°25'1.30"S 106°47'10.69"E         |

#### 2.3. Statistical analysis

Data were analyzed using IBM SPSS Statistics 23.0 software package. Data were presented in the form of mean and standard deviation. Impact of leachate discharge on river water quality was analyzed using Independent $t$-test at $p$-value ≤0.05 to compared the statistical differences between the means of upstream and downstream river water samples.

### 3. Result and Discussion

#### 3.1. Leachate characterization

Cipayung Landfill has been operating since 1984 and is classified as a mature landfill. However, the measured average of raw leachate temperature of around 34.81°C, TSS of 72.33 mg/L, pH of 7.83, BOD of 3,959.63 mg/L, COD of 6,860 mg/L, TN of 373.33 mg/L, Hg of 0.0016 mg/L, and BOD/COD ratio of 0.58 indicate that the leachate characteristics resemble an intermediate landfill. This deviation is due to the mixing of young leachate and old leachate since the solid waste dumping system in Cipayung Landfill does not use cell system to produce leachate with the character between young and old leachate (intermediate). The comparison between the leachate characteristics in Cipayung Landfill and the typical leachate is shown in Table 2. Characteristics of Cipayung Landfill leachate tends to be alkali which is typical of leachate in Indonesia [13]. However, the pH value is still within the range of values 6–9 appropriate for biological life. While leachate temperature is in the range of 33.8°C–36.4°C, and still in accordance with the optimum temperature of microorganisms, which is equal to 25°C–35°C [14]. Mature leachates with BOD$_3$ concentrations 100-200 mg/L are less polluted than young leachates 2,000–30,000 mg/L [14]. The young landfill has BOD$_3$/COD ratio 0.4-0.6 indicated that biological activity in the acid phase of anaerobic degradation, while mature landfill with BOD$_3$/COD ratio 0.02-0.5 produced stabilized leachate indicated with low COD concentration and low biodegradability [14]. The BOD$_3$/COD ratio of Cipayung Landfill leachate is 0.58 so that leachate can be treated by biological processing [15].

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Table 2. Comparison of Cipayung Landfill leachate characteristics and typical leachate.

| Parameter         | Cipayung Landfill (33 years) | Young landfill (<2 years) | Mature landfill (>10 years) |
|-------------------|------------------------------|---------------------------|-----------------------------|
| Temperature (°C)  | 34.81 ± 1.393                | -                         | -                           |
| TSS (mg/L)        | 72.33 ± 2.517                 | 200–2,000                  | 100–400                     |
| pH                | 7.83 ± 0.058                  | 4.5–7.5                   | 6.6–7.5                     |
| BOD (mg/L)        | 3,959.63 ± 993.711            | 2,000–30,000              | 100–200                     |
| COD (mg/L)        | 3,680 ± 2,182.212             | 3,000–60,000              | 100–500                     |
| TN (mg/L)         | 373.33 ± 93.305               | 500–1,500                 | 50–200                      |
| Hg (mg/L)         | 0.0016 ± 0.00135              | -                         | -                           |
| BOD/COD           | 0.58                         | 0.4–0.6                   | 0.02–0.5                    |

Table 3. Average ± standard deviation and removal percentage of the parameters in the leachate treatment plant.

| Pond type | TSS (mg/L) | pH | BOD (mg/L) | COD (mg/L) | TN (mg/L) | Hg (mg/L) |
|-----------|------------|----|------------|------------|-----------|-----------|
| AP Influent | 72.33 ± 2.517 | 7.83 | 3959.63 ± 993.711 | 6860 ± 2182.212 | 373.33 ± 93.305 | 0.0016 ± 0.00135 |
| AP Effluent | 151 ± 6.00 | 8.0 ± 0.17 | 3894.77 ± 1064.242 | 9956.8 ± 530.288 | 793.33 ± 84.120 | 0.00076 ± 0.00033 |
| % Removal | -110% | -2% | 2% | -45% | -113% | 53% |
| FP Influent | 151 ± 6.00 | 8.0 ± 0.17 | 3894.77 ± 1064.242 | 9956.8 ± 530.288 | 793.33 ± 84.120 | 0.00076 ± 0.00033 |
| FP Effluent | 32.33 ± 2.517 | 7.97 | 3714.63 ± 258.802 | 6155.1 ± 1605.116 | 186.70 ± 70.00 | 0.0031 ± 0.00286 |
| % Removal | 79% | 0% | 5% | 38% | 76% | -307% |
| MP Influent | 32.33 ± 2.517 | 7.97 | 3714.63 ± 258.802 | 6155.1 ± 1605.116 | 186.70 ± 70.00 | 0.0031 ± 0.00286 |
| MP Effluent | 60.33 ± 2.517 | 8.07 | 3399.13 ± 1418.785 | 9525.6 ± 2040.284 | 334.43 ± 94.318 | 0.00072 ± 0.00028 |
| % Removal | -87% | -1% | 8% | -55% | -79% | 77% |
| Total % Removal | 17% | -3% | 14% | -39% | 10% | 55% |
| Leachate standard [17] | 100 | 6–9 | 150 | 300 | 60 | 0.005 |
3.2. Performance evaluation of leachate treatment plant

The results obtained for each treatment unit and the overall leachate treatment plant are presented in Table 3. The quality of Cipayung Landfill leachate in each treatment unit shows that the removal efficiency does not comply with the design criteria, implying that the effluent quality of Cipayung Landfill leachate does not meet the quality standard based on [17] for BOD, COD, and TN parameters. The examination results of the anaerobic pond leachate samples state that the TSS concentration of 72.33 mg/L at the influent has been increased to 151 mg/L at the effluent since the mud at the base of the pond was too high. The TSS concentration of the facultative pond effluent was 32.33 mg/L, indicating that the removal of suspended solids at facultative pond processing unit reached 79%. Although the TSS concentration rose back to 60.33 mg/L at the maturation pond effluent, the overall removal efficiency of TSS concentration could reach 17%, and the quality of leachate discharged has fulfilled the requirement. The pH values of leachate in all treatment units are still within the standard quality range. The pH value of the influent leachate is 7.8–7.9 which tends to be alkali. Therefore, the leachate treatment does not require a neutralization process as a pre-treatment because pH 6 is the lowest limit for anaerobic processing [18]. The pH value of the anaerobic pond effluent has increased, indicating that the anaerobic processing has entered the final stage, raising the alkalinity that allows the methane microorganism to live. Volatile acids will be converted to methane and carbon dioxide (CO₂), while organic matters will decrease since its solubility will drop due to the boosted pH value. Supposedly, the pH value will dwindle back in the maturation pond because of the organic matter hydrolysis in the aerobic process, which resulted in the decrease of pH value and mineral dissolution. The rise of pH value to 8.07 in the effluent can be brought by the lack of oxygen concentration in the aerobic treatment within the maturation pond. The BOD concentration decreased toward the end of treatment with a removal efficiency of 14%. However, the leachate effluent has not met the leachate effluent standard. The high BOD concentration is caused by the organic residues contained in the anaerobic treatment that cannot be degraded in abundant quantity [19]. COD effluent concentration of 9,525.6 mg/L has not met the quality standard. The concentration of COD effluent is increased due to the absence of aeration and the presence of organic material residues. The concentration of TN decreased by 6% removal until the end of treatment. However, the effluent concentration of TN of 334.4 mg/L has not met the leachate standard. The concentration of ammonia nitrogen within the range of 25–30 mg/L can be toxic to anaerobic microorganisms because it inhibits their growth, affecting the removal of BOD and COD [20]. The high concentration of TN in the Cipayung Landfill leachate lessens the efficiency of BOD and COD removal. The concentration of Hg effluent was 0.0007 mg/L, and the removal efficiency was 56%. High concentration of heavy metals can be toxic to Chlorella species that are the main species in the stabilization ponds system. The pH value of >8 can cause the metal ions to precipitate, and the treatment process of stabilization ponds can run as usual [21].

3.3. River water quality

The water quality of Pesanggrahan River is shown in Table 4. Temperature is a parameter of aquatic physics that affects the chemical reaction and reaction rate, aquatic life, and the suitability of water use for a specific designation [22]. Increased temperatures can lead to increased viscosity, chemical reactions, evaporation, and volatilization, as well as decreased water solubility of gases, and increased metabolic rate of aquatic organisms [23]. It is known that the Pesanggrahan River water temperature is 26.92 °C at S5, 26.32 °C at S6, and 27.94 °C at S7. In general, the value of leachate temperature that enters the water body does not significantly affect the water temperature based on the t-test (p=0.56) and fulfill the standard of Class III water body. The condition of the Pesanggrahan River water temperature has been in accordance with the optimum temperature conditions for the growth of phytoplankton in the waters, i.e. between 20 °C to 30 °C [23]. The TSS consists of mud, fine sand, and microorganisms caused by soil erosion and is carried into the body of water [23]. While the concentration of TSS in leachate is dominated by dead bacteria. The entry of TSS into the waters can cause turbidity in the water, and the effect on the rate of photosynthesis phytoplankton decrease, and water productivity decreases. Such conditions may reduce the supply of dissolved oxygen in water bodies [23], but TSS concentrations in waters are naturally not toxic. The concentration of TSS in
Pesanggrahan River due to the leachate discharge has not significant influence on the fishery interest, where it is known that the TSS concentration of the Pesanggrahan River water is 78 mg/L at S5, increased at leachate discharge (S6) of 95.67 mg/L, and 69.67 mg/L at S7. In general, the concentration of TSS leach into the water body did not significantly affect the water temperature of Pesanggrahan River based on the t-test (p=0.77) and met the Class III water body standard of 400 mg/L. Waters will have a negative impact on fisheries if TSS concentrations are greater than 400 mg/L [24]. The pH value of Pesanggrahan River water is 7.1 at S5, 6.6 at S6, and 6.67 at S7. Pesanggrahan River pH values fluctuated from upstream, stream on the leachate discharge, and downstream after being influenced by leachate discharges, but still within the range of the Class III water body standard. The pH values fluctuated in water bodies may be affected by the amount of organic matter and inorganic materials in water bodies. High organic matter in water bodies can increase the pH value due to the decomposition process of organic matter releasing CO\(_2\) and inorganic materials which generally contain high amounts of mineral acid [25]. Meanwhile, the pH value of leachate that enters the water body of 7.83 still meets the quality standard of leachate effluent pH, which is between 6 – 9. It shows that the leachate discharge does not significantly affect the pH water quality based on the t-test (p=0.452).

| Parameters | Sampling Locations | Acceptable Limits | p-value |
|------------|--------------------|-------------------|---------|
|            | S5                 | S6                | S7      | (26) |          |
| Temperature (°C) | 26.92 ± 0.934 | 26.32 ± 0.926 | 27.94 ± 1.270 | dev 3 | 0.56 |
| TSS (mg/L) | 78 ± 34.771 | 95.67 ± 25.968 | 69.67 ± 31.501 | 400 | 0.77 |
| pH        | 7.10 ± 0.872 | 6.60 ± 0.100 | 6.67 ± 0.231 | 6 - 9 | 0.452 |
| BOD (mg/L) | 78.10 ± 21.913 | 90.25 ± 72.761 | 87.17 ± 59.351 | 6 | 0.816 |
| COD (mg/L) | 111.6 ± 38.311 | 129.5 ± 116.673 | 133.5 ± 91.905 | 50 | 0.723 |
| DO (mg/L)  | 7.1 ± 0.498 | 5.93 ± 0.459 | 5.04 ± 0.821 | 3 | 0.02* |
| TN (mg/L)  | 1.43 ± 0.252 | 1.97 ± 0.058 | 1.90 ± 0.529 | 3 | 0.24 |
| Hg (mg/L)  | 0.00098 ± | 0.00108 ± | 0.00070 ± | 0.002 | 0.378 |

* Exceed the standard limits for Class III water bodies quality
** Significant at p ≤ 0.05

Organic matter is composed of carbon, oxygen, hydrogen, and some compounds containing nitrogen compounds [22]. According to Pratiwi [27], if the need for oxygen levels is not proportional to the addition of oxygen from the air as well as photosynthetic results of phytoplankton, it can lead to a decrease in dissolved oxygen concentration, and increase the concentration of BOD. BOD concentration in Pesanggrahan River flow exceeds Class III water quality standard 6 mg/L. Leachate discharge affects BOD concentration, that is by increasing the concentration of BOD at point S6, that is equal to 90.25 mg/L. This indicates that in the locations occur the process of decomposition of organic materials and oxidation of inorganic materials that require dissolved oxygen (deoxygenation). However, based on the t-test (p=0.816) showed that leachate discharge did not significantly affect BOD concentration in Pesanggrahan River. The COD concentration in the Pesanggrahan River flow increased after leachate discharge, i.e. 111.6 mg/L at S5, 129.5 mg/L at S6, and 133.5 mg/L at S7. The concentration of COD exceeds the standard of Class III water body of 50 mg/L. However, based on the t-test (p=0.723) showed that leachate discharge did not significantly influence COD concentration. COD concentrations are greater than BOD concentrations because the amounts of chemical compounds that can be chemically oxidized are greater than that of biological oxidation. DO serves as an indicator of water quality, which plays a role in the oxidation process and reduction of organic and inorganic materials [28]. The DO concentration depends on the mixing process, the movement of the
water mass, the process of photosynthesis, and the effluent of waste entering the body of water [23]. The higher temperature and water level also affect the low concentration of DO due to low atmospheric pressure. DO concentrations decreased from upstream to downstream after being affected by leachate discharge from Cipayung Landfill. The DO concentration at point S5 of 7.1 mg/L, 5.93 mg/L at S6, and 5.04 mg/L at S7. Reduced DO concentration in downstream is influenced by increasing concentrations of organic and inorganic materials in river water. In the downstream after leachate discharge occurs the decomposition process of pollutants through the decomposition of organic materials, and oxidation of inorganic materials that require DO or called deoxygenation process. If the reaeration rate progress is lower than the rate of deoxygenation or self-validating ability, it can cause the DO concentration to decrease faster until it reaches anaerobic condition [23]. Leachate discharge affects DO concentrations based on the t-test (p=0.02). Pesanggrahan River TN concentration increased by leachate discharge, which was 1.43 mg/L at S5, 1.97 mg/L at S6, and 1.90 mg/L at S7. But still complied with the Class III water body standard based on [29], that is 3 mg/L. The increasing of TN concentration due to leachate discharge was not significant based on the t-test (p=0.24). The concentration of Hg at leachate discharge was under the standard of Class III water body and did not give a significant influenced the Pesanggrahan River water quality based on the t-test (p=0.378). The heavy metals contained in river water are lower than the heavy metals contained in sedimentary sediments where heavy metal deposits, and reach 99% of the total amount of heavy metals in the waters [30]. Overall, leachate discharge from Cipayung Landfill caused an increase in the concentration of pollutants in Pesanggrahan River, especially the concentration of COD and BOD. It is known that BOD and COD parameters exceed the standard of Class III water body, while the temperature, TSS, pH, DO, TN, and Hg meet below the Class III water body standard.

4. Conclusions
This study concern on environmental problems related with solid waste landfilling, that is the impact of Cipayung Landfill leachate on the Pesanggrahan River water quality. Based on this study, Cipayung Landfill classified as mature landfill, but the measured BOD/COD ratio 0.58 showed that this landfill had a high biodegradability through the anaerobic phase. The effluent of Cipayung Landfill leachate treatment plant exceeds the leachate standard limit based on [17] for BOD, COD, and TN parameters. Leachate characteristics had high concentration of organic chemicals and influenced the water quality of Pesanggrahan River indicated by the increasing of BOD and COD concentrations which resulted in significant decreasing of DO concentrations. To improve the quality of leachate effluent, it is necessary to make physical improvements by redesigning the treatment unit according to the design criteria to ensure that leachate discharge to water bodies does not exceed the standard limit to prevent contamination of the environment. Establishing a constructed wetland is recommended as well since the climatic condition of the study area implies that this method is suitable and has a high potential to improve the leachate effluent quality by reducing the nutrients, suspended solids, algae, and BOD concentrations.

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