Rehabilitation Planning of Gedangkeret Landfill in Jombang Region

G R A Mujaddid\(^1\) and E S Pandebesie\(^1\)

\(^1\)Department of Environmental Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

Abstract. The Region of Jombang in East Java has Gedangkeret Landfill as its final solid waste management system. There are 50 transfer stations that are mostly located in the district of Jombang. The other transfer stations are located in the districts of Diwek, Peterongan, Mojowarno, Mojoagung, Plaso, Ngoro, Gudo, Perak, Sumobito. These transfer stations produce at least 76.11 tonnes/day of solid waste. The composition of the solid wastes dumped in this landfill is mostly food waste and plastic. The presence of biodegradable wastes will produce plenty of greenhouse gasses. The leachate produced is processed in stabilization ponds, but the value of BOD and COD is still below the quality standard. The Index Score of Gedangkeret Landfill is 538.48, indicating that the landfill needs to be rehabilitated. The rehabilitation plans comprise of dumping zone stabilization, drainage system, leachate processing, landfill gasses management, and greenbelt plan. The dumping zone planning is based on population projection. The drainage system planning is based on the Jombang climate condition. The leachate processes planning is based on the leachate flow rate on each dumping zone and its characteristics. The greenbelt planning is based on the CO\(_2\) production and the conversion of the methane gasses.

1. Introduction

Jombang is a region in East Java Province which has a population density of 38,556 person/km\(^2\). The Region of Jombang has 50 transfer stations spread in its districts. Most of those are located in the district of Jombang, as the capital district of Jombang Region. These transfer stations accommodate solid waste from housings and traditional markets. The solid wastes would then be transported to Gedangkeret Landfill. This landfill is located in the district of Jombang, 4.7 kilometers from the center of the region. There is a settlement on the north of the landfill with a distance of 540 meters. On the far west side of the landfill, there is Brantas River with a distance of 4.9 kilometers.

Gedangkeret Landfill was first operated in 1994 after the Decision Letter of Jombang Mayor number 26 in 1993. It was first operated as an open dumping site, without the presence of cover soil. But, Gedangkeret Landfill is now operated as a controlled landfill, with a coverage of soil in the period after the completion of a cell. The landfill now is 8.7 hectares and will be expanded to 33 hectares. Each of the solid wastes from the transfer stations is transported to a landfill in Gedangkeret in the district of Jombang by dump trucks and arm roll trucks. Some trucks transport the solid wastes by only 1 ritation from each location, but some trucks can transport solid wastes with 2 or 3 ritations from each location like from a traditional market. The composition of the solid wastes depends on its producer. Food waste and plastics are the most commonly found type of waste in the solid waste composition. The composition of Jombang’s solid waste is shown in Table 1.
Table 1. Solid Waste Composition in Gedangkeret Landfill

| Solid Wastes                     | Composition (%) |
|----------------------------------|-----------------|
| Rapid Biodegradable Wastes       | 57.24           |
| Slowly Biodegradable Wastes      | 27.58           |
| Total Biodegradable Wastes       | 84.83           |

The rehabilitation planning is used to keep the environment around the landfill safe by changing the dumping method to a sanitary landfill. A sanitary landfill is a landfill system that minimizes impacts on public health [1]. This planning ensures that solid waste would not impact much especially by the solid wastes dumping construction, landfill gasses, and landfill leachate. The landfill gasses mostly comprise of methane and carbon dioxide that can harm the atmosphere [2], and leachate production can harm surface water and groundwater [3].

2. Materials and Methods

The data needed for the rehabilitation planning are:
- Total population,
- Contour of the landfill,
- Composition of the solid waste,
- Jombang climate data,
- Leachate flowrate, and
- Leachate characteristics.

The methods used to plan the rehabilitation are counting the projection of the total population to estimate future solid waste generation, counting the landfill gasses from the composition, evaluating the drainage system from Jombang climate data, and evaluating the existing stabilization pond by the leachate flowrate and characteristics.

3. Results and Discussion

3.1 Passive Zone Stabilization

Stabilization of solid wastes can be done by rearranging existing rubbish heap based on the rubbish heap criteria according to Minister of Public Works Regulation number 3 of 2013. Each solid waste cell must have a slope of less than or equal to 1: 3 to prevent any possible landslides. All landfills should be compacted using heavy equipment so that the waste density becomes large or the waste becomes very solid. After the waste is compacted then the waste should be covered with a cover soil with a volume of 20% of the volume of waste. Each cell should also be given an operating road for heavy equipment and trucks as wide as 4 m. The following figure shows an illustration of the ratio of the width and height of the slope as well as the location of the operating road in the landfill cell.

![Figure 1. Illustration of landfill slope and operating road](image)

3.2 Solid Waste Projection

The calculation of population projections was done using the geometric method. Projections using this method assume that population development automatically multiplies with population growth. This method does not pay attention to when there is a decline in development. Jombang Regency still has a population density that is classified as a medium city, so the geometric projection method is suitable to
be applied to calculate the population in the coming year. Calculation of population projections using the geometric method uses the following formula:

\[ P_n = P_0 + (1 + r)^{dn} \]  

(1)

Where, 
- \( P_0 \): Population number in the first year
- \( P_n \): Population number in the year \( n \)
- \( dn \): Periode of time
- \( r \): Average percentage of increasing population number

After the calculation, it was found that the number of Jombang Region’s population in 2033 would be 1,370,030 people.

Calculation of the projected solid waste generation was done by counting the waste generated by each individual in Jombang Regency. Research by Damanhuri states that in small or medium cities, the amount of waste generated is 0.2 kg per person per day [4]. The value of 0.2 kg per person per day was then multiplied by the number of residents to get the daily garbage generation value. The daily waste generation is generated by the entire population of Jombang Regency, but in fact, the people in Jombang Regency still have the habit of burning garbage, especially in rural communities. In addition to the limitations of waste transportation and the available TPS capacity, waste services in Jombang are still limited.

The percentage of services was calculated from the approach of the number of existing piles. In 2017, the landfill scales data stated that the generation of waste in Gedangkeret landfill was around 30,000 tonnes for total household waste or household-like waste. The calculation of projections used a percentage value of existing solid waste services of 20% in 2017. Then it was projected to increase by about 1% per year for household waste services. A 1% increase in services was chosen with consideration of the trend of solid waste services in previous years which increased gradually but not significantly. In this plan, the reduction of source waste is ignored by considering the existing condition of Jombang Regency waste that has not done a massive reduction of waste at the source. Table 2 shows the calculation of daily and annual household waste projections that have been multiplied by the percentage of solid waste services.

After knowing the mass of the solid wastes projected, then the mass was converted to volume by density multiplying. The density of the solid wastes compacted in the landfill is 689.77 kg/m³. The number of the projected solid wastes is shown on the following table.

**Table 2. Projected Solid Wastes**

| Tahun | Mass of Solid Wastes (tonnes) | Volume of Solid Wastes (m³) |
|-------|------------------------------|-----------------------------|
| 2017  | 30,854.21                    | 44,154.80                   |
| 2018  | 32,406.56                    | 46,376.34                   |
| 2019  | 33,975.30                    | 48,621.33                   |
| 2020  | 35,560.57                    | 50,889.97                   |
| 2021  | 37,162.51                    | 53,182.48                   |
| 2022  | 38,781.26                    | 55,499.04                   |
| 2023  | 40,416.96                    | 57,839.85                   |
| 2024  | 42,069.73                    | 60,205.09                   |
| 2025  | 43,739.73                    | 62,595.00                   |
| 2026  | 45,427.07                    | 65,009.72                   |
| 2027  | 47,131.95                    | 67,449.54                   |
| 2028  | 48,854.48                    | 69,914.61                   |
| 2029  | 50,594.78                    | 72,405.11                   |
| 2030  | 52,352.99                    | 74,921.25                   |
| 2031  | 54,129.32                    | 77,463.33                   |
| Tahun | Mass of Solid Wastes (tonnes) | Volume of Solid Wastes (m³) |
|-------|-----------------------------|-----------------------------|
| 2032  | 55,923.89                   | 80,031.49                   |
| 2033  | 57,736.81                   | 82,625.93                   |

3.3 New Dumping Zone Planning
The total accumulation of waste is used to calculate the land requirements for new landfill zones that will be needed. The land requirement calculation was carried out the same as the calculation that was done in the waste stabilization zone planning. The height regulation used was 16 meters (4 meters depth, 12 meters height). The number of cells above the soil surface was 8 cells with a cell height of 1.5 meters. The number of cells below the ground surface was 4 cells with a cell height of 1 meter. The form factor used was 0.55. The estimated land area requirement was 10.5 hectares. New landfill zones were planned using the area method. The planned area method would have a basin with excavation planning or cut and fills systems. The basis of each zone was planned with a 2 mm thick geomembrane layer to prevent leachate seepage into the ground which would result in groundwater pollution. The reason for choosing geomembrane as a base layer was that there was no need for soil compaction so that planning could be carried out ideally according to existing criteria. Planning for new landfill zones requires adjustments to existing landfill sites. The landfill zone is planned to be 2 units with the first zone having an area of 6 hectares planned to operate for 6 years and zone two with an area of 7 hectares planned to operate for 7 years. The construction of the landfill zone would be carried out in stages starting with the first landfill zone which is immediately built to collect waste from 2023 and the construction of the second landfill zone would start before 2025 so that in that year it could be ready to receive waste entering the landfill. The embankment was planned for 2 – 3 years more than the calculated necessary age to allow time for the transition of new land planning to a new landfill or new land.

Hoarding zone cells were planned using a stable slope system with a slope of 1: 3 for height and width. The planned height of cells below the ground surface is 1 meter per cell with a total cell count of 4 meters. The width of the slope would be 3 meters with a planned operating road for trucks and heavy equipment 4 meters wide. The planned height of cells above ground level is 1.5 meters per cell with a total of 8 cells. Slope width is 4.5 meters with a planned operating road width of 4 meters.

3.4 Drainage Construction
Drainage in the landfill is needed to drain water as soon as possible to the nearest river so that there would be no flood in the landfill. Flood in a landfill area can potentially affect the waste, causing leachate to infiltrate into the soil. The infiltration of leachate into the soil will make the groundwater be polluted by leachate.

Drainage planning of an area begins with a rain analysis to get the rainfall formula used to calculate the rainfall intensity in that area. The rain intensity value is then used to calculate the rain discharge. Rainfall is used to calculate drainage channel dimensions. The rainfall data used were from 2015 to 2017. The average (R) of the rainfall values in Jombang according to the rainfall data table is 194 mm. Rainfall data were obtained from the Jombang Regency Water Service.

The Gedangkeret final deposit area (TPA) currently has an existing drainage channel. In this research, 2 types of calculations were carried out, the calculation of the existing drainage analysis and the planning of a new drainage channel for the new zone plan. Calculation of the existing channel dimensions in this research obtained the minimum dimension that must be met in order to avoid flood in Gedangkeret landfill area. Drainage channels are also attached to the Gedangkeret landfill drainage layout.

Drainage canals were calculated throughout the landfill area, especially around the landfill zone. The calculation of drainage from the flat area and the landfill zone area is different because the rainwater that flows through the landfill zone has a short running time (t₀). This happens because
water flows from the top point of the hoarding zone. Drainage canals were calculated using PUH 25, so that during the operation of the landfill it would still be in progress to avoid flooding. Channels were planned around the exhaust zone and landfill operation road leading to a low contour towards the river in the northern part of the landfill.

Runoff discharge value is used to get the value of channel accumulation discharge. A channel accumulated discharge is a discharge in a channel flowing water from runoff directly to the channel and also water from the previous channel. The calculation of accumulated channel discharge must consider the contour where the direction of flow is towards the river which is at the lowest contour of the landfill site.

The dimensions of the channel are planned to be shaped like the existing channel, which is the U-shape. The calculation of channel dimensions was done using the Manning formula with a ratio of width and height of the channel being 2 : 1. Figure 2 shows an illustration of the shape of the calculated channel.

![Figure 2. Illustration of U-Ditch used](image)

After finding out the dimensions of the channel, a freeboard calculation (Fb) was then added to get the total height of the drainage channel. Then, the value of flow velocity in the channel was recalculated to ensure that the value still met the minimum criteria of 0.6 m/s.

### 3.5 Landfill Leachate Piping Construction

Leachate is a liquid that comes from the process of decomposition of waste that dissolves harmful compounds. Leachate has a very high concentration of BOD and COD compared to domestic wastewater. This is because in leachate, the components in the waste that contain a lot of pollutants have decomposed. Leachate water might contaminate groundwater if a landfill zone is not given a base layer and pipelines to channel leachate [5].

The leachate piping system is divided into two, namely primary piping and secondary piping. The primary pipe is the main channel that directly connects the zone to the Leachate Treatment Plant, while the secondary pipe is a pipe that is in the middle of the zone with the function of capturing leachate from the bottom of the zone and channeling it to the primary pipe.

This research plans leachate piping system with a fishbone pattern, with the reason that it can capture leachate flow in the middle of the dumping zone. The pipes used are 300 mm HDPE pipes for primary pipes and 150 mm HDPE pipes for secondary pipes, the meetings between the primary and secondary pipes are given a control tub each with 50 cm long, 50 cm wide and 50 cm high which can be connected by vertical ventilation for gas piping. Primary pipe outlets of the piping system are connected to the Leachate Treatment Plant using primary pipe dimensions with slope criteria of 2%.

### 3.6 Leachate Treatment Plant

Leachate from the landfill zone is channeled to leachate treatment. In this research, a new leachate treatment plant was planned to process leachate from the new dumping zone. Leachate treatment
plants used would be stabilization ponds which are anaerobic ponds, facultative ponds, and maturation ponds. Leachate discharge was calculated from the annual leachate production of the landfill zone. Leachate production is influenced by the infiltrated rainwater discharge into the waste and water content in the waste. Leachate production in Gedangkeret landfill comes from several landfill storage zones. In this research, leachate production is categorized as follows:

- Passive zone 1 leachate production
- Passive zone 2 leachate production
- Existing active zone leachate production
- New zone 1 leachate production
- New zone 2 leachate production

Leachate discharged from passive zone 1, passive zone 2 and the existing active zone would be channeled to the existing leachate treatment plant, while leachate discharged from new zones 1 and 2 would be channeled to the new leachate treatment plant.

The new landfill zone planned would have a wider area compared to the size of the previous landfill zone. Therefore, the leachate flowrate generated by this new zone would certainly be greater than the leachate flow rate produced by the existing stabilization pond. The amount of leachate discharge was determined from the amount of solid wastewater content that would enter, as well as the area of the zone which collects rainwater. Both of these greatly affect the amount of leachate flowrate entering the leachate treatment plant. In other cases, there are factors such as evaporation, water use for gas reactions, and field capacity of solid waste that can reduce a small amount of leachate flow rate.

In this research, leachate discharge from the new landfill zone is planned to enter the more effective leachate treatment plant. The units used in this planning are anaerobic ponds, aeration ponds, and maturation ponds. The three units are conventional processing that is effective and does not require quite expensive costs such as processing using chemicals.

According to regulation of ministry of environment and forestry number 59 of 2016 concerning Leachate Water Quality Standards for Final Processing Activities, a heavy metal parameter in the form of mercury must be set aside to a minimum of 0.005 mg/L. In further planning, it is necessary to measure the parameters of mercury contained in the Gedangkeret landfill leachate. Then it is recommended to process the mercury content with a phytoremediation system in the form of wetland.

According to research by Ambarsari and Qisthi, phytoremediation using Phragmites australis plants in the construction of artificial wetlands can absorb up to 99.8% mercury content in wastes [6]. This method can be used in Gedangkeret landfill to reduce the mercury content in leachate water. Phragmites australis is a kind of large grass that is often found on the edge of water banks or muddy soils, in the area of Java this plant is often referred to as glagah or perumpung.

3.7 Landfill Gas Management
Solid wastes dumped up at the landfill will begin aerobic and anaerobic reactions. Waste that is covered by soil or other cover will experience anaerobic reaction because there is no contact with free oxygen. The anaerobic reaction in waste will produce greenhouse gases in the form of methane gas and carbon dioxide gas. Methane gas takes up 47.4%, while carbon dioxide gas occupies 47%, nitrogen 3.7%, and the rest is other gas. [2]. This shows that the composition of methane and carbon dioxide gas in solid waste is almost the same, around 50:50.

The gas produced by the landfill needs to be managed so as not to damage the environment. In addition, methane gas can also be reused as an alternative fuel if refined and further processed. Landfill gas management planned in this thesis is in the form of gas pipeline design and calculation of the volume of gas produced by all landfill waste until the operational year of the landfill is completed. Calculation of the amount of gas generation was done based on the gas triangle method according to Tchobanoglous. In this method, waste is divided into two types, Rapid Biodegradable Waste (RBW) and Slowly Biodegradable Waste (SBW). This method explains that the amount of gas produced by
the landfill will peak at a time, then it will decrease with the year, so the resulting graph illustrates the shape of a triangle. RBW produces the maximum amount of gas in the first year and then decreases until the fifth year, while SBW produces the maximum amount of gas in the fifth year then decreases until the fifteenth year. [1]

Solid waste that is classified as RBW includes food waste and garden waste, while SBW includes cardboard, plastic, cloth, rubber, leather, and paper. Metal, glass, hazardous waste and residual waste are considered the solid waste that cannot be degraded biologically.

Gas pipes or gas vents would be used to channel the gas produced by anaerobic reactions in the waste to the gas storage or combustion of the gas so it does not come out freely into the air becoming greenhouse gases. In this research, gas ventilation is planned with the following criteria:

- Pipes used are 165 mm diameter PVC.
- The distance between the gas pipes in one lane pipeline is a maximum of 50 m.
- The gas that comes out of the gas vent is burned, or if there is a gas storage and treatment facility then it is directed to the gas reservoir.
- The height of the gas vent follows the height of the rubbish heap (each layer plus 50 cm).
- Ventilation pipes are installed from the base of the landfill gradually in each layer of waste and connected from the control tubs of leachate pipes.

The gas that has been collected is handled by combustion alternatives by the flaring method or is utilized as electrical energy using advanced processing. Both of these alternatives have their respective advantages in processing the gas emitted by waste. The flaring method is recommended for use in the temporary treatment of landfill gas to ensure that no greenhouse gas emissions are released into the air, causing air pollution.

Flaring is a method of burning methane gas emissions produced by the anaerobic reaction of waste decomposition. The flaring method is the most commonly used processing method [1]. The flaring process requires oxygen to do perfect combustion. Therefore, a special study and planning are needed relating to the management of methane gas produced by Gedangkeret landfill solid waste.

3.8 Greenbelt Planning

Greenbelt is a line of trees or other vegetation that is intentionally planted around the landfill area that serves to reduce carbon dioxide gas produced from the combustion process or solid waste flaring, as well as emissions resulting from the operation of vehicles such as trucks and excavators inside the landfill. Calculation of the amount of carbon dioxide gas emissions from waste decomposition activities has been done before, but the amount is a combination of the amount of methane gas with a ratio of 1:1.

In this research, all methane gas produced by landfills will be burned through a flaring system so that the amount of methane gas released needs to be converted to CO$_2$ gas that would be generated. The chemical reaction formula for methane combustion or flaring is as follows:

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$ (2)

The relative mass value of the methane gas compound is 14 while the carbon dioxide gas is 44. So, through the law of mass comparison, it can be concluded that from 1 gram of methane gas burned, 2.75 grams of carbon dioxide gas is produced.

The total landfill emissions in 2019 deriving from garbage, trucks, and excavator vehicles were 191,404 tonness. Every year, the number of trucks and excavators would increase linearly with the amount of waste entering the landfill.

Additionally, according to the environmental baseline data of Gedangkeret TPA, Jombang Regency, many teak trees can be found growing in the forest area around the TPA. According to Karyadi, teak trees have the ability to absorb carbon dioxide by 20,565 kgCO$_2$/day with a maximum planting distance of 12 meters between trees [7].
In 2032, the maximum annual carbon dioxide gas production that would occur in Gedangkeret landfill from the emissions of all activities in the landfill was estimated at 544,397 tonnes. The planned Gedangkeret landfill would be 2525 meters long. Therefore, if planting of teak is planned with a 12 meters distance between trees, there would be 73 teak trees. A total of 73 teak trees planted around the TPA can reduce as much as 4.13 tonnes CO$_2$/day or 1501.25 tonnes CO$_2$/year.

4. Conclusions
The existing dumping zones need to be recontoured, and the passive zones need to be surrounded by berms to prevent landslides. The total population in 2020 was estimated to be 1,274,219 people. The existing dumping zone could only be filled until the end of 2019, so the zone needs to be expanded. Rainwater would be channeled through the U-ditch drainage system into the river. The composition of the Gedangkeret Landfill is mostly rapid biodegradable waste that produces much of landfill gasses. The landfill gasses need to be flared before being released to the atmosphere. The leachate characteristic was below the quality standard. The existing stabilization ponds can be modified by using a surface aerator to remove the organic content of the leachate. Greenbelt planning is also needed to reduce the amount of carbon dioxide produced by landfill activities.

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