Study of Leachate Penetration in Shallow Groundwater Around Jabon Landfill Sidoarjo

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Abstract. This study was conducted at Jabon Landfill located in Jabon District, Sidoarjo. Jabon Landfill has been operating since 2003 with the Controlled Landfill system. Laboratory test results of samples taken at 18 sampling points in the east, south and west zones of the landfill for Total Dissolved Solid (TDS), Turbidity, Manganese (Mn) and Chloride (Cl-) parameters showed that they were higher than the quality standards except Iron (Fe). According to the groundwater elevation, contaminants were dispersed towards the east and south of the Landfill. Leachate pollutant index was 7.70 which means it was moderately polluted. A well was used as a source of clean water but the well water has a quality status of moderately polluted and lightly polluted. The distance and depth of initial groundwater have a significant effect on the status of water quality.

Keywords: Community Perception, Leachate, Pollution Index

1. Introduction

The Truss Landfill is one method for municipal soil waste disposal. This type of facility known to have caused serious groundwater pollution by leachate leaks [4]. Leachate is a liquid substance that is produced in the process of decomposition of waste and it has very strong odor. Leachate is generated due to the entry of water into landfills which can result in contamination of groundwater, especially shallow groundwater (dug well). In time, leachate might seep into the soil and cause contamination of subsurface water.

Shallow groundwater is a primary source water for people who are not connected to PDAM water distribution network. Generally, shallow groundwater is found at a depth of ± 15 meters. According to literature, the landfill facility being studied covers all the rubbish in Sidoarjo, causing waste to decompose faster and produce pollutants that can pollute groundwater [6]. In addition, clean water has been very difficult to obtain in Jabon, because its groundwater has been polluted by leachate. For that reason, this study aims to find out the dispersion of pollutants due to leachate.

This study reviewed two aspects, the environmental aspect and aspect of society. The environmental aspect study was done by performing analysis of the well water compared to quality standards set in Regulation Minister of Health no 492/IV/2010 and then determining the water quality status using the Pollutant Index Method according to Minister of Environment No. 115 of 2003. In addition, the effect of well distance and groundwater
elevation to water quality status will also be examined. The aspect of society study is needed to determine the community’s perception of consuming well water, the effect of pollution of the Jabon landfill leachate on the well water of residents around the landfill.

2. Materials and methods
The study location is the area around the Jabon landfill. On the north of the landfill site is porong river. Porong river is ± 600 meters from Jabon landfill so the sampling location was in the east, south and west of the landfill.

Well water sampling was done by Purposive sampling method which was done at distance A (0 - 250 meters), distance B (251 - 500 meters), distance C (501 - 1000 meters) from the pollutant source (Jabon Landfill). For each distance (A, B, C) from the landfill site, 6 samples were taken, including 2 wells from the east, 2 wells from the west, and 2 wells from the south. Therefore, there were a total of 18 samples point with 2 repetitions each. Site selection with random sampling was done based on visual appearance. Sampling of shallow groundwater was done by grab sampling once at each point.

2.1. Data Collection
The data needed in this study include primary data and secondary data:
1. Plotting position coordinates of each well (sampling site)
2. The parameters studied were Manganese (Mn), Iron (Fe), Chloride (Cl⁻), Dissolved Total Solids (TDS) and turbidity. Quality standard used was that set in Regulation Minister of Health no 492/IV/2010
3. Measurement of the depth of groundwater
4. Results from questionnaires distributed to public
5. Observation of the physical condition of the wells
6. Administrative data of Jabon i.e. rainfall data and sub district data
7. Lithology log bor data, include permeability, porosity, and soil type

Figure 1. Sampling Points Location
2.2. Determination of Water Quality Status with Pollution Index (IP) Method

Article 2 of the Minister Environment No. 115 of 2003 contains Guidelines for Determining the Status of Water Quality. The formula used is as follows:

\[ IP_j = \sqrt{\frac{C_{jT}^2 + M + C_{jR}^2}{2}} \]  

(1)

Environmental aspect was studied by direct field surveys and interview to take samples of community well water and then the status of water quality was determined using the Pollution Index method.

2.3. Questionnaire Data Collection

Data collection technique used in this study was by distributing questionnaires. Calculation of the number of respondents was done using the Slovin formula below [7].

\[ n = \frac{N}{1 + N \cdot d^2} \]  

(2)

With a total of 1118 families in the study area, a number of 96 respondents were obtained as samples using the Slovin formula, analyzed by statistical methods using SPSS 22 software. The study on the aspect of society was carried out by analyzing results of the questionnaire to determine the community's perceptions of the consumption of well water so the role of well water could be understood.

3. Results and Discussion

Groundwater Elevation can be obtained from the difference between the depth of groundwater and the elevation of a place. The function of groundwater elevation is to find out the direction of the movement of water flow, as water moves from high elevation to low elevation.

![Figure 2. Contour Map Elevation MAT of Jabon Landfill Area](image)
From Figure 2, it can be seen that the dominant leachate seepage contaminants flowed to the east and south. This also corresponds to the direction of river water flow.

The results of data collection of the geological conditions of drilling were relatively homogeneous. The results of the permeability tests ranged from $10^{-5}$ - $10^{-9}$ m/s and no tectonic structures such as faults were found in the area around the landfill (see Table 1 and Table 2).

| Depth       | Soil Description                                      |
|-------------|-------------------------------------------------------|
| 0 – 1.0 meters | • Topsoil, sandy clay  
                 | • Brown, dry                                             |
| 1.0 – 2.7 meters | • Sandy clay                                            |
|             | • Coarse grained and dark gray                        |
| 2.7 – 2.9 meters | • Sandy clay                                            |
|             | • Dark grey                                             |
| 2.9 – 4.3 meters | • Sandy Clay                                            |
|             | • Medium grained and dark colored gravel               |
| 4.3 – 6.0 meters | • Sandy clay                                            |
|             | • Smooth clay, black in color                          |
| 6.0 – 20 meters | • Clay and mud                                         |
|             | • Black                                                |

Source: PT Gamma Epsilon Indonesia, 2016

| Depth       | Average Permeability (k) m/s | Average Permeability (k) m/h |
|-------------|------------------------------|-----------------------------|
| 3 – 5 meters | $8.344 \times 10^{-8}$       | $0.030 \times 10^{-4}$      |
| 5 – 10 meters | $4.195 \times 10^{-7}$       | $0.151 \times 10^{-4}$      |
| 10 – 15 meters | $4.675 \times 10^{-8}$      | $0.017 \times 10^{-2}$      |
| 15 – 20 meters | $1.474 \times 10^{-7}$     | $0.053 \times 10^{-2}$      |

Source: PT Gamma Epsilon Indonesia, 2016

3.1 Description of Well
The total number of samples was 18 wells. The average well depth was <10 meters. The sampling of well water was done at every well which had a distance of 11 meters from any pollutant source, e.g. a bathroom, a toilet, or a farmhouse. (see Table 3).

| Well No | Distance from Landfill (meter) | Well Description |
|---------|-------------------------------|------------------|
| 1       | 219 from East                  | -    √   -   √   √   √   -    √   √ |
| 2       | 241 from East                  | -    √   -   √   √   √   -    √   √ |
Application of dug wells as water source is not good in terms of health because dug wells are easily contaminated from seepage which can reduce the quality of well water, but occurrence of pollution can be prevented. Health requirements for clean water supply refer to Appendix IV of Minister of Public Works and Public Housing Regulation No 27/PRT/M/2016 concerning the operation of drinking water supply systems.

Leachate water quality data were an important component in the analysis of data. Leachate sampling was carried out at the inlet of the drainage which was not coated with concrete and directly bordered the soil surface, so it was assumed that the leachate would be infiltrated into groundwater flow.

### Table 4. Results of Quality Analyses of Jaban Landfill Leachate

| Parameter      | Leachate Quality | Quality Standard / Threshold Limit (*) |
|----------------|------------------|----------------------------------------|
| Temperature (°C) | 28.4             | -                                      |
| Turbidity (NTU) | 76.55            | 5                                      |
| pH             | 6.35             | 6.5 – 8.5                              |
| TDS            | 2978.5           | 500                                    |
Measurement of well depth, well height, groundwater elevation and well diameter at the study location referred to SNI No. 6989.58 in 2008 (see Table 5).

### Table 5. Description of the Physical Condition of Well

| Well No | Position | Distance (m) | Depth H (m) | Well Height h (cm) | Diameter (cm) | Groundwater Level P (m) | Land Elevation (m) | Groundwater Elevation (m) |
|---------|----------|--------------|-------------|--------------------|---------------|------------------------|--------------------|--------------------------|
| 1       | East     | 219          | 6.0         | 55.5               | 72.0          | 2.2                    | 3.3                | 1.1                      |
| 2       | East     | 241          | 6.6         | 49.7               | 61.5          | 2.5                    | 1.4                | 1.1                      |
| 3       | East     | 379          | 7.0         | 32.4               | 62.7          | 3.2                    | 2.1                | 1.1                      |
| 4       | East     | 485          | 8.7         | 72.5               | 92.0          | 3.4                    | 2.2                | 1.2                      |
| 5       | East     | 971          | 9.0         | 39.0               | 70.6          | 3.4                    | 2.4                | 1.0                      |
| 6       | East     | 1000         | 9.5         | 49.0               | 66.0          | 3.5                    | 2.6                | 0.9                      |
| 7       | South    | 196          | 6.5         | 41.0               | 71.7          | 1.6                    | 2.8                | 1.2                      |
| 8       | South    | 211          | 7.7         | 23.0               | 62.4          | 1.6                    | 2.8                | 1.2                      |
| 9       | South    | 353          | 7.8         | 30.5               | 66.0          | 2.9                    | 1.8                | 1.1                      |
| 10      | South    | 444          | 8.5         | 72.0               | 68.0          | 3.1                    | 2.1                | 1.1                      |
| 11      | South    | 710          | 8.6         | 39.5               | 73.0          | 4.4                    | 3.0                | 1.4                      |
| 12      | South    | 990          | 9.5         | 42.3               | 68.5          | 3.9                    | 3.0                | 0.9                      |
| 13      | West     | 103          | 6.7         | 41.0               | 70.3          | 3.5                    | 1.8                | 1.7                      |
| 14      | West     | 197          | 6.9         | 64.0               | 69.5          | 4.0                    | 2.0                | 2.0                      |
| 15      | West     | 391          | 7.5         | 59.5               | 66.0          | 4.8                    | 3.0                | 1.8                      |
| 16      | West     | 464          | 8.5         | 70.7               | 75.0          | 4.8                    | 3.0                | 1.8                      |
| 17      | West     | 707          | 9.8         | 39.5               | 74.0          | 5.6                    | 3.6                | 2.0                      |
| 18      | West     | 911          | 10.0        | 47.0               | 69.5          | 5.0                    | 1.2                | 3.8                      |

### 3.2 Water Quality Status of Shallow Groundwater

Determination of the well water quality status around the landfill area was done using the Pollutant Index (IP) Method as mentioned in the Decree of the State Minister of Environment Number 115 of 2003 concerning Guidelines for Determining Status of Water Quality listed (see Table 6). A Pollutant Index Score in the range of 0-1.0 means good condition, 1.1-1.50 lightly polluted, 5.0-10.0 moderately polluted, and >10 heavily polluted.

### Table 6. Water Quality Status of Shallow Groundwater Around Landfill

| Number | Sample | Distance (m) | Position | Pollutant Index | Water Quality Status         |
|--------|--------|--------------|----------|-----------------|------------------------------|
| 1      | Well 1 | 219          | East     | 5.31            | Moderately Polluted          |
| 2      | Well 2 | 241          |          | 4.79            | Lightly Polluted             |
| 3      | Well 3 | 379          |          | 4.41            | Lightly Polluted             |
| 4      | Well 4 | 485          |          | 3.23            | Lightly Polluted             |
| 5      | Well 5 | 971          |          | 2.98            | Lightly Polluted             |
IOP Conf. Series: Earth and Environmental Science 506 (2020) 012034    doi:10.1088/1755-1315/506/1/012034

| Number | Sample | Distance (m) | Position | Pollutant Index | Water Quality Status |
|--------|--------|--------------|----------|-----------------|----------------------|
| 6      | Well  6| 1000         |          | 1.91            | Lightly Polluted     |
| 7      | Well  7| 196          | South    | 5.45            | Moderately Polluted  |
| 8      | Well  8| 211          |          | 3.50            | Lightly Polluted     |
| 9      | Well  9| 353          |          | 2.91            | Lightly Polluted     |
| 10     | Well 10| 444          |          | 2.17            | Lightly Polluted     |
| 11     | Well 11| 710          |          | 1.32            | Lightly Polluted     |
| 12     | Well 12| 990          |          | 1.06            | Lightly Polluted     |
| 13     | Well 13| 103          | West     | 2.76            | Lightly Polluted     |
| 14     | Well 14| 197          |          | 2.56            | Lightly Polluted     |
| 15     | Well 15| 391          |          | 1.42            | Lightly Polluted     |
| 16     | Well 16| 464          |          | 1.91            | Lightly Polluted     |
| 17     | Well 17| 707          |          | 1.39            | Lightly Polluted     |
| 18     | Well 18| 911          |          | 0.93            | In Good Condition    |
| 19     | Leachate| 0           |          | 7.70            | Moderately Polluted  |

Leachate sample was found to have the largest Pollution Index (IP) of 7.70 with the status of moderately polluted water quality. The 1st well closest to the east of Jabon landfill had an IP of 5.31 with a moderately polluted quality status, while well 2 to well 6 which were the farthest in distance from the landfill were lightly polluted. The higher the value of its pollutant index, the more polluted the well water was.

On the south of Jabon landfill, well 7 with a distance of 196 m from the landfill had an IP of 5.45, categorized as moderately polluted, while well 8 to well 12 had a status of lightly polluted water quality. On the west of Jabon landfill, well 13 to 17 had a status of lightly polluted water quality. Wells 13 and 14 had a distance of 103 and 197 meters from the landfill, and although they were on the west of the landfill, it still allowed leachate to seep into shallow groundwater at that distance. However, well 16 had a higher value of Pollutant Index because the well had a farm enclosure, where the cage was less than 11 meters away from the well so pollution could occur.

3.3 Aspect of Society

Before data collection was carried out, first step was to test the validity and reliability of the questionnaire. Validity test was used to measure the accuracy or validity of a questionnaire. A questionnaire is said to be valid if the questions in the questionnaire can express something that will be measured by the questionnaire [3]. Validity measurement was done with the Person product moment correlation method (significance <0.05 and correlation > 0.3).

Residents who use well water for cooking and drinking were 6.25% and 2.08%, for washing 94.79%, and 100% for bathing. Well water was also used to water plants 92.71% and in farms 82.29%. Moreover, 92.71% of the respondents who bought clean water from other parties would usually experience abdominal pain and 39.58% often felt nauseous.

72.92% of the respondents mentioned that their well water would feel sticky on the skin when used for bathing, 89.58% often felt itching on the skin, 72.92% would often have diarrhea or abdominal pain and 39.58% often felt nauseous. Factors causing the itching could be the TDS content exceeding normal limits, chemical contamination or bacterial factors. From the results of the questionnaire, 6.25% and 2.08% of the respondents were still dependent on using well water to cook and drink because they were less able to buy clean water from other parties (Figure 3).
Figure 3. Role of Well Water

The study area had turbid well water, and this is evidenced by the questionnaire results where 92.71% of the correspondents answered they observed turbid water, while 92.71% of the respondents said the water tasted salty and 78.13% said the well water had odour (Figure 4).

Figure 4. Physical Condition of Well Water

The smell and turbidity of shallow groundwater of the respondents was found in wells located quite close to the landfill active land. The location was in a settlement which was <1000 m from the landfill. The respondents also said if well water was left to stand for one night in a bath or in a container there would be sand deposits. The manganese content was found to be very high, so the clear water that was stored for a while would yield yellow, red, brown and even black deposits. This could happen because the collected water had been mixed with air, so if the iron and manganese content dissolved in the water was high, it would turn into rusty grains which would eventually settle at the bottom of a container.

93.75% of those surveyed from the surrounding community also mentioned that there had never been any inspection of the quality of well water in the area around the landfill, either from the landfill authorities or the government.
3.4 The Effect of Distance and Depth of Groundwater on Water Quality Status

The variables used in this analysis were the independent variables namely Distance (X1) and Groundwater Depth (X2). While the dependent variable was Status of Water Quality (Y). Statistical tests were carried out by multiple regression methods.

Table 7. Multiple Regression Test

| Model        | Unstandardized Coefficients | Standardized Coefficients |
|--------------|----------------------------|---------------------------|
|              | B  | Std. Error | Beta | t   | Sig.  |
| 1 (Constant) | 8.940 | 1.344 |        | 6.653 | .000  |
| Distance (X1) | -.003 | .001 | -.629 | -3.238 | .005  |
| Depth Groundwater (X2) | -.793 | .170 | -.758 | -4.653 | .000  |

From the SPSS output, it was found that the significant value of the Distance variable (X1) was 0.005 and the significant value of the Groundwater Depth variable (X2) was 0.000. Because the significant values of 0.005 and 0.000 were lower than 0.05, according to the basis of decision making in the T test, it can be concluded that Distance (X1) and the Initial Depth of Groundwater (X2) affected the Status of Water Quality (Y) (see Table 7).

Distance had an important role in seeing the distribution of contaminants. Distance to landfill and water quality status tend to be directly proportional [10]. In other words, the closer the distance of the dug well to the pollutant source, the greater of pollution. Dug wells provide water that comes from groundwater that is relatively close to the surface of the soil, making it susceptible to contamination through permeation from pollutant sources. The distribution of leachate pollution can be identified to a depth of 15 meters [9]. The influence of the depth of the groundwater level on the concentration of pollutants is in accordance with [8], which stated that the depth of the groundwater level would determine the ability to decrease the content of pollutants. The shallower the surface of the...
groundwater, the greater there is the likelihood of pollution. Groundwater level is used as a reference to be able to see the effect of pollution.

3.5 Recommendation
1. In accordance with groundwater elevation contour which decreases to the east and south, settlements should be located to the west of Jabon landfill so that they do not become contaminated by leachate dispersion.
2. It is advisable to consider health requirements for the physical quality of dug wells that supply clean water, referring to Appendix IV of the Regulation Minister of Public Works and Public Housing Number 27 / PRT / M / 2016 concerning the operation of drinking water supply systems to minimize pollution of well water.
3. Wells should be made at a depth of >15 meters to avoid pollutants.
4. The government should pay attention to clean water sources in Jabon area, especially in the area near the landfill.

4. Conclusion
1. The leachate from the landfill had a pollutant index of 7.70 which means it was moderately polluted. Water wells to the east and west of the landfill at a distance of 219 and 196 meters had the status of moderately polluted water quality, while those at a distance more than that had the quality status of lightly polluted water. The wells in the west zone of the landfill had a status of lightly polluted water quality, but well 18 at a distance of 911 meters had a water quality status of in good condition with a pollutant index of 0.93.
2. The roles of well water for the surrounding community were for cooking and drinking at 6.25% and 2.08%, for washing at 94.79%, while 100% of the population used well water for bathing. 92.71% of the respondents answered that they observed turbid water in the wells, 92.71% of them said the water tasted salty, and 78.13% said that the well water smelled. 72.92% answered that when the well water was used for bathing it would feel sticky on their skin, 89.58% often felt itching on their skin, and 72.92% often suffered from diarrhea. So, there was a significant effect of the independent variable (X), namely Jabon Landfill on the dependent variable (Y), which was the well water quality. There were also significant effects of Distance (X1) and Depth of Groundwater (X2) on the Status of Water Quality (Y).

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