Controlling model of dispersed leachate in the landfill site of Tamangapa Makassar Indonesia

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Controlling model of dispersed leachate in the landfill site of Tamangapa Makassar Indonesia

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Abstract— **The Tamangapa landfill, the only operational landfill in Makassar City since 1995, is the subject of this study. The objective of this research was to determine the direction of leachate flow generated by the waste in the Tamangapa landfill and simulate remediation management for the dispersed leachate, which has contaminated the groundwater flowing into community wells. Modflow + MT3DMS software was employed to model the groundwater flow direction, leachate dispersion, and pumping simulations. The concentrations of interest in this research were iron (Fe) and manganese (Mn). The modeling results revealed that the leachate from the Tamangapa landfill spreads from northwest to southeast, following the groundwater flow direction, and contaminates the community wells. Subsequently, a remediation management plan was developed using modeling techniques, specifically through pumping simulations with a pumping rate of 1500 m^3/day. This pumping process was conducted until all the contaminated leachate in the community wells was removed, which was estimated to require a pumping duration of 15 months.**

Keywords— ***Leachate; Remediation; Modflow; Groundwater.***

Introduction

In Indonesia, it is common for landfills to still operate using the open dumping system. This system involves piling up waste in a large open area without the use of geotextile layers or leachate channels, leading to the leachate seeping into the ground [1]. As a consequence, groundwater pollution occurs in the vicinity of the landfill. This is suspected to be the case for the only operational landfill in Makassar, namely the Tamangapa landfill located in the Antang area, which covers an approximate area of 16.8 hectares.

A landfill, also known as a final disposal site, is a place where waste is isolated or buried to prevent environmental disturbances [2]. In [2], Damanhuri and Padmi (2010) found that in Indonesia, there are three common methods of waste disposal in landfills: (1) Open dumping is the most widely used waste management system in Indonesia as it is the simplest approach, where waste is simply dumped at a landfill site without any further treatment. (2) Controlled landfill, also known as a land-filled cover system, is an improvement over open dumping but not as advanced as a sanitary landfill. Daily incoming waste is spread and compacted using heavy machinery. Then, the compacted waste is covered with soil every five or seven days. This is done to reduce odors, control fly breeding, and minimize the release of methane gas. Drainage channels, leachate collection systems, operational control posts, and methane gas control facilities are also established. (3) Sanitary landfill, also known as engineered landfill, is a method where waste is systematically placed in a concave area, spread, compacted, and covered daily with a soil cover at the end of each operating day. The soil cover is compacted to a thickness of 10% -15% of the waste layer to prevent the spread of diseases, dust, and lightweight waste that could contaminate the surrounding environment [2].

Initially, the Tamangapa landfill was designed to meet the waste disposal needs for a period of 10 years. However, it has been in operation for nearly 23 years, surpassing its intended lifespan [3]. Currently, there are suspicions of pollution in the Tamangapa landfill in Makassar City, resulting in detrimental effects on the surrounding environment, particularly in terms of declining groundwater quality. Furthermore, the proximity of the Tamangapa landfill to residential areas, schools, places of worship, and offices exacerbates the situation, leading to frequent complaints from residents about unpleasant odors emanating from the landfill.

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In waste management, one crucial aspect is the proper management of leachate. Failure to manage leachate effectively can lead to environmental and public health problems. Leachate, which contains bacteria and other harmful substances, can spread through surface water and groundwater systems [4]. The Tamangapa landfill itself has a leachate containment pond designed to minimize the presence of bacteria and other hazardous compounds in the leachate. However, the leachate pond at the Tamangapa landfill is not functioning optimally in its operation. Additionally, there are pipe damages that result in the leakage of leachate from the waste piles to the leachate pond, as well as damages to the pond itself, allowing the leachate to infiltrate the soil and contaminate the groundwater in the surrounding area of the Tamangapa landfill.

To mitigate the impact of groundwater pollution, remediation efforts can be implemented [5]. Remediation refers to activities aimed at cleaning up contaminated areas. The objectives of remediation [6] include (1) reducing the causes of groundwater contamination by pollutants, (2) preventing the migration of contaminants, and (3) restoring the function of groundwater as a source of water for living organisms that depend on it. One method of groundwater remediation is through groundwater pumping. The purpose of pumping is to reduce the concentration of pollutants in the groundwater, thus minimizing their spread. Pumping locations and pumping rates are determined by analyzing the direction of groundwater flow carrying the contaminants. These locations and rates can then be simulated using software such as PMWin [7] to assess the effectiveness of the pumping strategy. Based on the background previously described, research is needed to determine the direction of leachate dispersion and the extent to which the leachate pollutes the surrounding environment of the Tamangapa Landfill, as well as the efforts made to address the problem of lymphatic fluid pollution at the Tamangapa Landfill in Makassar.

In this research, for the first time, the mapping of leachate dispersion in the Tamangapa Landfill area in Makassar was conducted and followed by groundwater remediation management using numerical modeling. This study is highly beneficial as preliminary information for the government and local communities to address groundwater pollution caused by leachate in the vicinity of the Tamangapa Landfill in Makassar.

Materials and Method

The Tamangapa Landfill in Makassar was located in the Manggala District, Tamangapa Village, precisely at coordinates of 5.1752°S and 119.4935°E, approximately 15 km from the center of Makassar City. The Tamangapa Landfill began operating in 1995 and remains the only urban solid waste disposal site in the area. Since its establishment in 1995, the landfill s area has expanded from approximately 14.3 hectares to 16.8 hectares.

Figure 1. Research location.

Administratively, the Tamangapa Landfill was located in the Manggala District and was in close proximity to residential areas. As a result, local residents often complained about unpleasant odors emanating from the landfill, especially during the rainy season. The Manggala District was one of the districts in Makassar City whis was not directly border to the sea. It covers an area of 24.14 km^2, which is approximately 13.73% of the total area of Makassar City, with a population density of 4,101 people/km^2.

From the Tamangapa Landfill location, there are several other activity centers such as places of worship, schools, and offices located approximately 1 km away. Since 2000, several residential areas have been established around the landfill, including Antang Housing Complex, Indonesian Navy Housing Complex, Graha Jannah Housing Complex, Griya Tamangapa Housing Complex, and Taman Asri Indah Housing Complex.

Based on observations by residents in the areas surrounding the Tamangapa Landfill, 15 open wells were identified. Coordinates were recorded for each well using a Geodetic GPS [8]. The water table depth was measured using a measuring tape. The obtained data from the measurements are as follows: .

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Table 1. Groundwater Depth Measurements in Observation Wells.

Lokasi	Water table depth (m)	Well casing elevation (m)	Water table elevation from mean sea level =F-(A-B)	Coordinate		
				X	Y	Z
	A	B	C	D	E	F
Well 1	5.40	1.10	13.25	775627.05	9427359	17.553
Well 2	1.83	0.71	19.12	775566.02	9427463	20.238
Well 3	2.80	0.77	11.13	775647.07	9426866	13.164
Well 4	0.99	0.41	12.38	775893.07	9426528	12.962
Well 5	1.22	0.65	13.56	776263.52	9426367	14.134
Well 6	1.40	0.71	13.16	776339.26	9426509	13.846
Well 7	1.38	0.60	12.80	776356.66	9426700	13.578
Well 8	1.40	0.65	12.34	776459.55	9426876	13.085
Well 9	1.33	0.62	12.01	776476.58	9426897	12.716
Well 10	1.68	0.65	11.74	776495.15	9426942	12.767
Well 11	3.05	0.77	10.42	776582.03	9427234	12.704
Well 12	0.94	0.79	13.20	776114.58	9426495	13.351
Well 13	1.08	0.97	17.49	775904.75	9427395	17.598
Well 14	3.63	0.87	12.69	776223.5	9427785	15.449
Well 15	3.85	0.79	12.00	775707.3	9426895	15.062

The soil in the Tamangapa Landfill area is formed by the Baturape-Cindako formation, which is composed of volcanic rocks resulting from volcanic eruptions. It is a type of sandy clay soil with hydraulic conductivity values listed in Table 2 and porosity values listed in Table 3.

Table 2. Hydraulic conductivity values on several soil types [9].

Soil Type	Hydraulic conductivity (K) (cm/second)
Clayey sand	10^{-2} to 5×10^{-3}
Fine sand	5×10^{-2} to 10^{-3}
Silty sand	2×10^{-3} to 10^{-4}
Silt	5×10^{-4} to 10^{-5}
Clay	10^{-6} to 10^{-9}

Tabel 3. Porosity values on several several soil types [10].

Soli Type	Porosity Values
Uniform gravel and sand	0,25-0,50
The mix of gravel and sand	0,20-0,35
Coarse sand	0,25-0.35
Medium sand	0,35-0,40
Fine sand	0,40-0,50
Dolomite, (*fractured*)	0,07-0,11
Silty sand	0,39
Silt	0,35-0,50

Due to the limitations of available hydrological and hydrogeological data (such as soil stratigraphy, recharge, and specific storage), simplifications have been made in some hydrogeological data while still considering secondary data from previous studies. The aquifer type in the research location was assumed to be an unconfined aquifer because of the presence of a free water table. The domain used in the numerical modeling is a 3-dimensional model. The obtained soil contours from topographic measurements were inputted as surface contours of the topmost layer in the domain. The number of rows used is 286 with a width of 5 meters, while the number of columns used is 210 with the same width. In the vertical direction, six layers with varying thicknesses were used. The coordinates in the domain were then adjusted to match the coordinates obtained from geodetic GPS measurements to ensure a realistic analysis concept. In this research, the groundwater table was considered to be in a steady-state condition, and the groundwater simulation was run for a period of 25 years.

The hardware equipment used for the research includes Geodetic GPS and a measuring tape (Roll Meter). The

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software tools used include Ms. Word, Ms. Excel, PMWin, Trimble Business Centre, Surfer, and Google Earth. The required data for the research include topographic data, groundwater table elevation data, soil properties data around the Tamangapa Landfill, and relevant literature. The GPS Geodetic instrument was used for topographic measurements using the Real Time Kinematic (RTK) method. The results of the topographic measurements were processed to create contour maps around the Tamangapa Landfill location.

After obtaining the field measurements, the next step was processing the collected data. The topographic data obtained from the field was downloaded from the Geodetic GPS and processed using Microsoft Excel and Surfer software to create contour maps of the area surrounding the Tamangapa Landfill in Makassar. The contour maps can be combined with the measurements of groundwater table elevation and soil properties using the PMWin application. The results from the PMWin analysis provide information about the dispersion direction of the leachate that has mixed with the groundwater. It helped to determine the locations for groundwater pumping and the pumping rates required to mitigate the leachate dispersion in the groundwater. The leachate dispersion results can be visualized on a contaminated area map. By displaying the dispersion direction of the leachate, it was expected to identify the potential contamination pathways that could affect the clean water sources for the communities living around the Tamangapa Landfill.

The topographic map was created based on measurements using a Geodetic GPS instrument using Static and RTK Radio methods. The measurement results were obtained from the controller that is connected to the Geodetic GPS during the measurement process. The coordinate data collected from the controller were processed using the Trimble Business Centre software. The results from the static measurements were processed to obtain benchmark coordinates, and then the benchmarks from the RTK measurements were corrected to match the benchmarks obtained from the static data. The Trimble Business Centre application was used to process the coordinates of all measured points, which were exported in Microsoft Excel format. The data in Microsoft Excel format were used to create the topographic map, which then processed to generate the groundwater table map.

After obtaining the topographic map of the area around the landfill, the next step was to model the leachate dispersion simulation. The modeling was performed using MODFLOW and MT3DMS in the PMWin software [11]. Once the direction of leachate dispersion in the groundwater was known, the next step was to remediate the groundwater using groundwater pumping methods.

Results and Discussion

Results of numerical modeling of direction and velocity of groundwater flow.

The results of the numerical modeling of the groundwater table elevation contours using MODFLOW can be seen in Figure 2. From Figure 2, it can be observed that the groundwater table elevation in the Tamangapa Landfill location varies significantly, with the lowest groundwater table elevation at 10.5 meters and the highest at 18.9 meters above sea level. Generally, the groundwater table in the landfill area is relatively higher compared to the surrounding locations, ranging from 13 meters to 18 meters above sea level. This information indicates a significant potential for groundwater contamination in the surrounding areas of the landfill due to leachate dispersion. Therefore, further research is highly necessary to investigate this matter in detail.

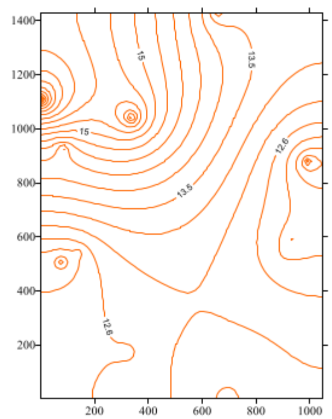

Figure 2. Groundwater table elevation contour at the research location (unit in meters).

Figure 3 shows the direction and velocity of groundwater at the Tamangapa Landfill location. The highest groundwater velocity occurs in the western part of the landfill on the northern side, with velocities ranging around 3 cm per day, and generally, the groundwater flows towards the east from the landfill. In the eastern part of the landfill, there is a former school that is no longer in use, and based on direct field observations, the wells used by the school have started to turn yellow and emit an odor. Further analysis is needed to determine the cause of well contamination in that area, but the initial assumption is that it is due to leachate contamination from the landfill.

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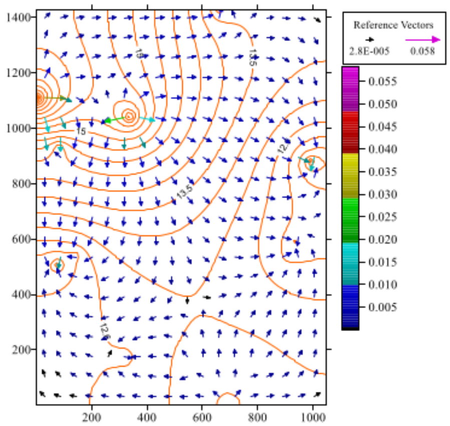

Figure 3. Groundwater direction and velocity in research location (unit in meter).

The modeling results of leachate distribution at theTamangapa Landfill

The damage to the pipeline that carries leachate from the impermeable layer to the leachate treatment pond has rendered the leachate treatment facility at Tamangapa Landfill non-functional. As a result, some of the leachate water infiltrates into the soil layer. Additionally, the inner part of the leachate pond has also developed cracks, causing the leachate water stored in the pond to infiltrate into the soil layer. Some of the leachate water is also flowing into the surrounding marshland near Tamangapa Landfil.

In this modeling, the leachate treatment pond is considered as the point of seepage, which is the source of pollution. The concentrations present in the leachate include iron (Fe), fluoride (F), hardness (CaCO3), chloride (Cl), manganese (Mn), nitrate, nitrite, sulfate (SO4), and permanganate value. However, in this study, the concentrations of iron (Fe) and manganese (Mn) are being examined. High concentrations of Mn and Fe, if consumed, can have health impacts on the community. One of the health impacts of iron is that it can damage the intestinal lining and cause irritation to the eyes and skin, while manganese can lead to neurological disorders and even death.

According to the Minister of Health Regulation Number 492 of 2010 regarding the Requirements for Drinking Water Quality, the allowable concentration of Fe is 0.3 mg/l and Mn is 0.4 mg/l. However, laboratory test results of the leachate water quality indicate that the Fe content is 9.69 mg/l and Mn content is 0.46 mg/l. Therefore, the leachate water that has infiltrated into the groundwater has the potential to cause contamination of the surrounding groundwater, as its concentrations have exceeded the limits set for drinking water or clean water. This can pose a risk to the local community, as many people still rely on well water for their daily needs.

Simulation modeling of leachate dispersion in TPA Tamangapa, Makassar, is conducted for a period of 25 years. This assumes that the TPA has been operational since 1995 until 2020, representing its lifespan. The simulation starts from the first year of TPA Tamangapa's operation and assumes that leachate contamination has occurred in the surrounding groundwater. The source of contamination is located in the leachate control pond, which should have been a leachate pond.

The leachate pond is assumed to be unable to function optimally due to pipe damage that transports the leachate to the pond and damage to the pond itself. The volume of leachate that infiltrates into the soil is measured through direct observations at the leachate pond for 24 hours, while disregarding factors such as evaporation, variations in incoming waste volume, and seasonal changes.

Pumping of contaminated groundwater is conducted at two locations. The first location is around the leachate control pond, aiming to control the horizontal and vertical spread of the leachate. The second location is around the contaminated community wells, aiming to extract the contaminated groundwater. The pumping duration is ideally within a period of less than 2 years. This timeframe is considered optimal to mitigate the spread and minimize the potential risks associated with the contaminated groundwater.

Based on the simulation results using MT3DMS modeling, it is found that the concentrations of Mn and Fe move from the northwest direction towards the east of TPA Tamangapa, following the direction of groundwater flow. The dispersion pattern of Mn and Fe concentrations curves towards the east. As time progresses, the concentrations of these substances also increase. Considering the simulated 25-year duration and the soil conditions in TPA Tamangapa, which consist of clay-mixed sand, a porosity value of 0.35 and a hydraulic conductivity value of 5 m/day are used.

Based on the MT3DMS modeling, the distribution of Iron (Fe) concentration is obtained and can be observed in Figures 4 to 6. Figure 4 represents the modeling results of Fe contaminant dispersion after one year, with the lowest concentration at 0.3 mg/l and the highest concentration at 5.2 mg/l, covering an area of 5689.28 m².

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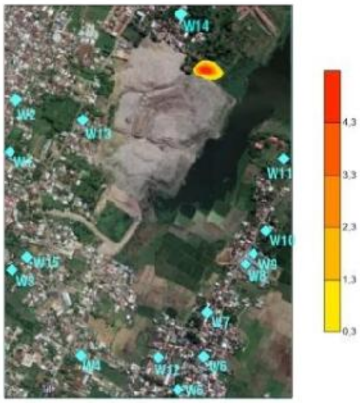

Figure 4. One year modeling result of Fe contaminant.

Figure 5 presents the modeling result of Fe contaminant dispersion over a period of 10 years, with the lowest concentration at 0.3 mg/l and the highest concentration at 7.12 mg/l, covering an area of 35,432.67 m^2.

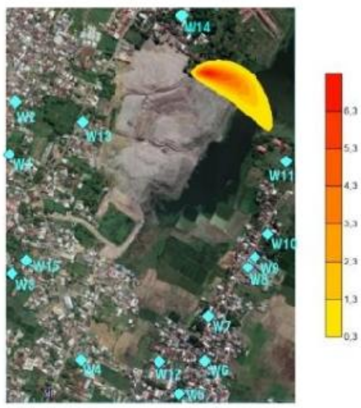

Figure 5. Ten years modeling result of Fe contaminant

Figure 6 displays the modeling result of Fe contaminant dispersion over a period of 25 years, with the lowest concentration at 0.3 mg/l and the highest concentration at 7.12 mg/l, covering an area of 56,394.27 m^2.

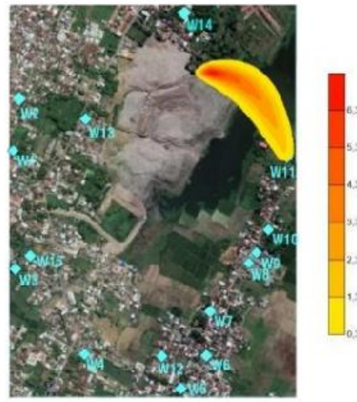

Figure 6. Twenty five years modeling result of Fe contaminant.

From the modeling results of Fe contaminant, it can be observed that the Fe concentration has reached the community wells with values exceeding the maximum allowable limit stated in Minister of Health Regulation Number 492 of 2010 regarding the Requirements for Drinking Water Quality, which is 0.3 mg/l for Fe content. It can be concluded that the Fe dispersion in well 11, which is used by the community, has exceeded the maximum required value.

Next, the results of the MT3D modeling of Manganese (Mn) contaminant dispersion can be seen in figures 7 to 9. Figure 7 shows the modeling results of Mn contaminant dispersion over one year, with the lowest concentration being 0.1 mg/l and the highest concentration being 0.24 mg/l, covering an area of 2,220.56 m2.

Gambar 7. One year modeling result of Mn contaminant.

Figure 8 presents the results of the modeling of Manganese (Mn) contaminant dispersion over 10 years, with the lowest

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concentration being 0.1 mg/l and the highest concentration being 0.33 mg/l, covering an area of 12.016.44 m^2.

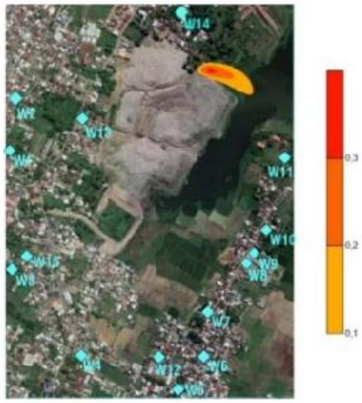

Figure 8. Ten years modeling result of Mn contaminant.

Figure 9 displays the results of the modeling of Manganese (Mn) contaminant dispersion over 25 years, with the lowest concentration being 0.1 mg/l and the highest concentration being 0.33 mg/l, covering an area of 21.417.93 m^2.

Figure 9. Twenty five years modeling result of Mn contaminant.

Based on the results of the Manganese (Mn) contaminant dispersion, the concentration of Mn in the vicinity of the community well remains within the safe limits according to the Minister of Health Regulation No. 492 of 2010 concerning the Requirements for Drinking Water Quality, which states that the permissible level of Mn is 0.4 mg/l.

Groundwater Remediation Management at Tamangapa Landfill

After obtaining the simulation of groundwater flow and leachate flow dispersion around the Tamangapa landfill, remediation is necessary to reduce the leachate flow that contaminates the groundwater used by the community as a source of clean water. The remediation management steps that will be taken include groundwater pumping at two points. The first point is located near the leachate treatment pond, which is the point where leachate seeps into the soil layer. The second point is located near the contaminated community well. This is done to redirect the leachate that has infiltrated the soil layer and is flowing with the groundwater back to the leachate treatment pond, away from the community well. The pumping rates used in this simulation are 300 m^3/day, 900 m^3/day, 1200 m^3/day, and 1500 m^3/day, with two pumping points. The pumping near the leachate treatment pond is carried out at coordinates 5°10'27.48"S, 119°29'33.67"E and at a depth of 12.4 m. The pumping near the community well is conducted at coordinates 5°10'30.24"S, 119°29'40.38"E and at a depth of 12.6 m.

In the pumping simulation with a rate of 300 m^3/day, it was conducted for 10 years, but not all of the dispersed contaminated groundwater has been fully pumped to the bottom of the aquifer. The pumping results for layer one can be seen in figure 10, and for layer six, it can be seen in figure 11. Similarly, in the pumping simulation with a rate of 600 m^3/day, it was conducted for three years, but the dispersed contaminated groundwater had also not been fully pumped to the bottom of the aquifer.

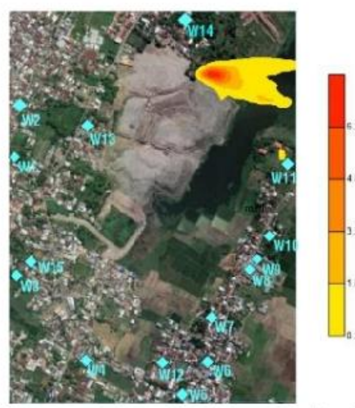

Figure 10. The pumping result at layer one with a flow rate of 300 m^3/day for three years.

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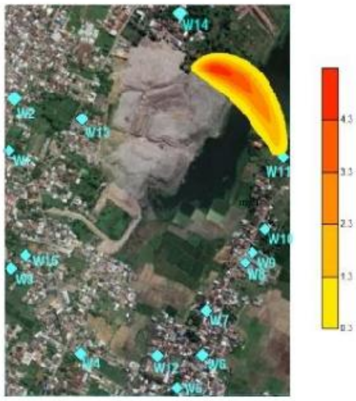

Figure 11. The pumping result at layer six with a flow rate of 300 m^3/day for three years.

Next, a pumping simulation was conducted using a discharge rate of 900 m^3/day simulated over three years, and the results remained the same, indicating that the contaminated groundwater had not been fully pumped out to the bottom of the aquifer. The pumping results for layer one are shown in Figure 12, and for layer six, they can be observed in Figure 13.

Figure 12. The pumping result at layer one with a flow rate of 900 m^3/day for three years.

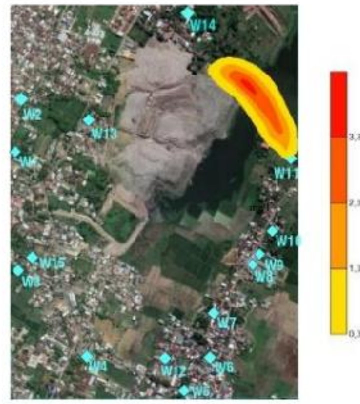

Figure 13. The pumping result at layer six with a flow rate of 900 m^3/day for three years.

Pumping simulation was performed again using a discharge rate of 1200 m^3/day for three years. However, the dispersed leachate still had not been fully pumped out to the bottom of the aquifer. The pumping simulation results for layer one can be seen in Figure 14 and layer six in Figure 15.

Figure 14. The pumping result at layer one with a flow rate of 1200 m^3/day for three years.

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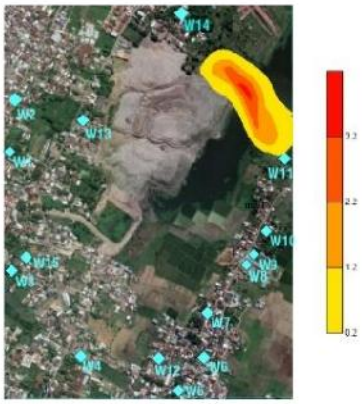

Figure 15. The pumping result at layer six with a flow rate of 1200 m^3/day for three years.

Then a final pumping simulation was conducted with a higher discharge rate of 1500 m^3/day. In this simulation, all the contaminated leachate groundwater had been pumped out completely to the bottom of the aquifer within 15 months. The pumping results for layer one can be seen in Figure 16 and layer six in Figure 17.

Figure 16. The pumping result at layer one with a flow rate of 1500 m^3/day for 15 months

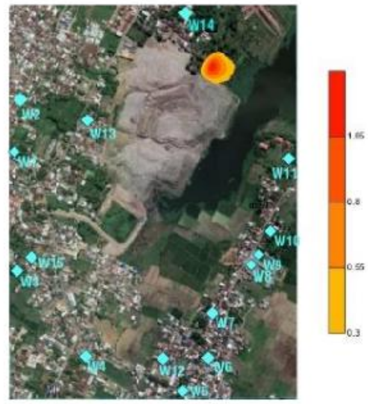

Figure 17. The pumping result at layer six with a flow rate of 1500 m^3/day for 15 months.

Conclusion

Based on the research findings, three important conclusions can be drawn regarding Tamangapa Landfill (TPA) and the issue of leachate distribution, as well as the remediation efforts undertaken. Firstly, it has been proven that the leachate distribution in the Tamangapa Landfill follows the direction of groundwater flow from the northwest to the east. This is evident from the steady-state simulation results, where the leachate follows the pattern of groundwater flow and can reach community wells. Heavy metal concentration analysis, such as iron (Fe) and manganese (Mn), indicates the presence of 0.41 mg/L of Fe and 0.13 mg/L of Mn in community wells. Unfortunately, the Fe concentration has exceeded the limit set by the Ministry of Health Regulation Number 492 of 2010 concerning Drinking Water Quality Requirements.

Secondly, as a remediation effort, groundwater pumping management was implemented at the Tamangapa Landfill using numerical modeling. The pumping method was carried out around the leachate treatment pond and the contaminated community wells. The results have shown that groundwater pumping with a discharge of 1500 m^3/day has proven to be the most effective option in addressing the spread of leachate present in the groundwater. The chosen pumping discharge was based on evaluations and calculations. With a groundwater pumping rate of 1500 m^3/day, it was estimated that the leachate dispersed in the groundwater can be addressed within 15 months..

From the research findings, it is evident that further actions are necessary to address the issue of heavy metal concentrations in the groundwater at the Tamangapa Landfill.

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The excessive concentration of Fe, which has surpassed the set limit, indicates the need for more intensive and sustainable remediation efforts. Groundwater pumping as a remediation measure has shown positive results, but continuous monitoring is required to ensure its long-term effectiveness. Moreover, further research is essential to evaluate the long-term impacts of leachate distribution and gain a deeper understanding of the hydrogeological conditions at the Tamangapa Landfill. These steps will provide a solid foundation to ensure safe drinking water quality and a healthy environment for the surrounding community.

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