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Evaluation Of Unconfined Groundwater Quality At Air Dingin Landfill in Padang City

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ABSTRACT

An evaluation of unconfined groundwater at the Air Dingin Landfill (TPA) in Padang City, West Sumatra, has been conducted to assess the impact of leachate on the water quality utilized by the surrounding community. Groundwater samples were collected from ten strategically selected points around the landfill, with support from JPS. The leachate characteristics analyzed included pH, temperature, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), total dissolved solids (TDS), total suspended solids (TSS), and the concentrations of heavy metals such as Pb, Cu, Mn, As, Cd, Cr, and Fe. A thermometer and a pH meter were employed to measure temperature and pH levels, respectively. The concentrations of heavy metals were determined using Atomic Absorption Spectroscopy (AAS), while BOD, COD, TDS, and TSS values were assessed through the gravimetry method.The test results for various parameters, including odor, taste, temperature, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and levels of heavy metals (Pb, Cu, Mn, As, Cd, Cr, and Fe), generally remain below the quality standards outlined in Indonesian Minister of Health Regulation No. 416 of 1990 and Government Regulation No. 82 of 2001. However, the pH levels of the unconfined groundwater measured between 3.04 and 6.05, which do not meet the Government's requirements for all test wells. Additionally, the leachate does not appear to impact the quality of the unconfined groundwater surrounding the Air Dingin Landfill. Overall, the groundwater quality in this area generally complies with the standards set forth in Minister of Health Regulation No. 416 of 1990 and Government Regulation No. 82 of 2001.

1. INTRODUCTION

The rapid growth and development of the population, particularly in large cities, has led to increasingly expansive residential areas, which in turn has caused a significant rise in the volume of both solid and liquid waste produced. According to Sulastri et al. (2016), a growing population correlates with an increase in the amount of waste generated. Additionally, they noted that not only is the volume of waste on the rise, but the types of waste are also diversifying rapidly, influenced by technological advancements (Lubis, 2020). Another consequence of this

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growth is the increase in leachate produced by waste. Soekmana (2010) emphasized that the management of urban, residential, and industrial waste poses a significant challenge for waste management in Indonesian cities.

Waste materials, whether they decompose quickly or linger for a long time, necessitate different handling technologies. Waste disposal sites are typically characterized by low-lying areas, depressions, or bodies of water such as rivers, ditches, lakes, and seas (Munawar, 2011). Biodegradable waste, including items like wood, paper, carcasses, leaves, and human waste, decomposes relatively easily (Sumantri, 2010). However, the sheer volume of organic waste can overwhelm natural processes, leading to negative consequences such as unpleasant odors (Katrin, 2024). In certain regions, this issue can promote algal blooms, which subsequently harm aquatic ecosystems. Conversely, non-biodegradable waste presents a more complex challenge, as synthetic materials like plastics, synthetic fibers, metals, and pesticides take an exceptionally long time to decompose in nature. This situation is further exacerbated by the fact that urban waste management in Indonesia continues to depend on centralized or conventional systems (Soekmana, 2010), (Saputra, 2020).

The largest contributors to waste generation include urban areas, residential neighborhoods, markets, shops, and industrial sites (Suharno, 2012). The characteristics of urban waste are highly varied, primarily due to the diverse range of activities within communities. This waste can consist of food scraps, wood, paper, organic matter, textiles, plastics, bones, glass, metal, and soil, among other materials (Suharno, 2012). Landfills play a crucial role; however, they can also negatively impact environmental quality. This decline is largely due to waste accumulation, which produces various pollutants, including foul-smelling gases, liquid waste that contaminates groundwater and river systems, and creates habitats for disease vectors.

Unused materials or product residues are referred to as waste, which can exist in solid, liquid, or gaseous forms. The decomposition of easily liquefied waste can lead to the formation of leachate or runoff. Leachate, generated from the breakdown of waste, food scraps, or plant matter when mixed with rainwater, poses environmental challenges that are intricately linked to issues of cleanliness, health, aesthetics, and comfort. As noted by Ehring in Munawar (2012), leachate that accumulates on the ground surface can contaminate both groundwater and surface water. Some of this leachate infiltrates the ground, while others flow on the surface toward lower elevations, reaching rivers. Eventually, the ocean and some of the water may evaporate due to wind currents and elevated temperatures. Landfills for waste, particularly those located near residential areas, river basins, springs, lakes, and other public facilities, are often perceived as zones for potential residential expansion. Consequently, the management of landfills requires careful attention to prevent pollution. One of the landfills designated for waste disposal in Padang City is the Air Dingin Landfill.

The Air Dingin Landfill is one of the primary waste processing sites nearing its maximum capacity in Padang City. Following the landslide at the Payakumbuh Landfill, waste production in Padang City has surged to 640 tons per day, with additional waste from Bukitinggi City and Payakumbuh now being directed to Air Dingin. According to reports from Tribunnews, Bukitinggi contributes between 75 and 90 tons of waste daily, while Payakumbuh sends between 30 and 84 tons per day. Currently, the capacity of the Air Dingin Landfill is 90% utilized. Nonetheless, the Head of the Padang City Environmental Agency has indicated that the landfill can still accept waste from outside Padang City. However, it is anticipated that storage capacity may reach overload by 2026, possibly even earlier than expected.

Near this landfill, air temperatures typically range from 23ºC to 31ºC, while humidity levels fluctuate between 70% and 85%. In 2023, the average annual rainfall was approximately 4,461 mm^3, which corresponds to a monthly average of 371 mm^3 and a daily average of 12 mm^3. The rainfall conditions are detailed in Table 1, and the location of the Air Dingin Landfill is illustrated in Figure 1.

The Air Dingin Landfill is situated on a gently sloping area that stretches from east to west, with a contour that is not particularly steep, as observed at the site. Measurements taken using the JPS (Journal of Land Use Surveying) indicate that the landfill is located at an elevation ranging from 37 to 60 meters above sea level, featuring a slope of approximately 3.8%. This slope extends both east to west and south to north, allowing leachate to flow naturally toward the west and north. Given the slope's characteristics, it is recommended that the leachate treatment pond or sterilization pond be positioned to the north.

Figure 1. Current condition of the Air Dingin Landfill

At present, there are twelve semi-permanent houses occupied by twenty-eight residents located to the north and west of the landfill. To the east, there are pens for cattle and chickens, while to the south, across the street, stand several permanent homes along with a place of worship. Residents access clean water for their daily needs by filtering water from wells that are dug at each residence.

Table 1. Rainfall in 2024 (Source: Meteorology, Climatology and Geophysics Agency. Data quoted from the publication "West Sumatra Province in Figures")

No	Months	Rainfall (mm3)	Number of Rainy Days (Day)
1	January	530.70	18.00
2	February	309.50	18.00
3	March	598.20	20.00
4	April	455.20	26.00
5	May	332.30	26.00
6	June	208.20	19.00
7	July	82.80	29.00
8	August	371.50	31.00
9	September	262.70	30.00
10	October	632.00	31.00
11	November	345.80	30.00
12	December	625.20	31.00

At the Air Dingin Landfill, the waste management system continues to rely on an open dumping method. Trucks deliver waste to a designated area where it is then spread out and compacted using bulldozers and excavators. Daily, approximately 370 to 400 tons of waste are deposited into the landfill. Waste is not sorted by type; however, scavengers manage to locate reusable materials among the discarded items. The application of geotextiles and geomembranes on the landfill's surface helps to minimize leachate infiltration and improves leachate management.

Leachate control is implemented manually by constructing drainage channels around the landfill. These channels are designed to collect leachate that escapes from waste piles, particularly during the rainy season when leachate production tends to increase. The collected leachate flows through PVC pipes into stabilization ponds located on the northern side of the landfill. These stabilization ponds serve to neutralize leachate, removing suspended materials and other floating debris that enter the ponds concurrently. Comprising several columns, the ponds facilitate the natural treatment of leachate to neutralize pollutants before it is discharged into the river. This leachate treatment method is utilized at the Air Dingin Landfill, benefiting from the area's tropical climate and consistent sunlight exposure. Consequently, this natural approach is more cost-effective than mechanical leachate treatment systems.

Based on the above conditions, it is necessary to research "The Effect of Leachate on Unconfined Groundwater Quality at the Air Dingin Landfill in Padang City".

The most important part of introduction is the state of the art of previous studies (literature overview or concept of theories); describe the gap analysis. State the objectives of the work. Hypothesis may be stated in gap analysis.

Provide general background in one paragraph. State of the art should be based on minimum of 5 references to justify novelty of the work (generally about 2-3 paragraphs). Describe the findings of each references instead of describing the references separately (two or more references may contain the same findings).

2. METHODS

A. Type of Research

The conducted research will employ a descriptive quantitative approach. In this study, the researcher aims to characterize the quality of shallow groundwater surrounding the Air Dingin Landfill by examining various physical and chemical parameters. The findings will be compared against the clean water quality standards outlined in Minister of Health Regulation No. 416 Permenkes/Men/X/1990 and Government Regulation No. 82 of 2001 regarding Water Quality Management and Water Pollution Control, as well as relevant SNI standards.

B. Sampling Techniques

The sampling method used was purposive sampling, where researchers took shallow groundwater samples from dug wells or existing wells located around the landfill. The sampling points were strategically arranged to ensure that the samples taken accurately represented the groundwater surrounding the landfill. The number of sampling points was ten, corresponding to ten sampling locations. More samples were taken from the west and north compared to the east and south. It is because the movement of groundwater at this landfill location tends to flow westward due to the lower topography of the western area compared to the eastern area. For more details, the map of the sampling point locations at the Air Dingin TPA can be seen in Figure 2.

Water is drawn from a dug well located 20 cm below the surface. When using a pump to extract the water, it is allowed to flow for 1 minute before samples are collected for testing. Sampling is conducted in the morning to avoid an increase in water temperature. The collected water samples are placed in sterile plastic bottles.

To ensure accurate positioning of the sampling point, researchers utilize JPS technology. This step is crucial for linking the sampling sites to their geographical coordinates. For further details, please refer to Table 2

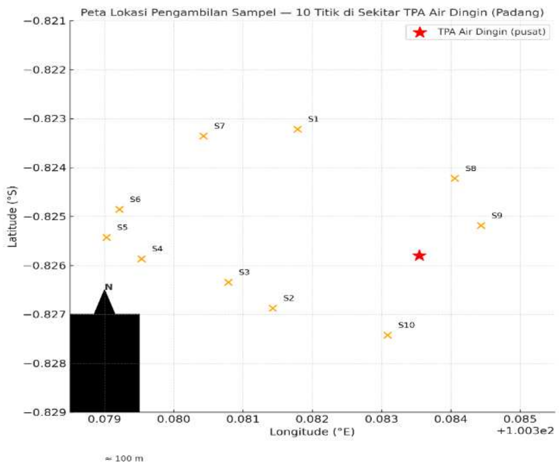

Figure 2. The map of the sampling point locations at the Air Dingin TPA

Table 2. Coordinates of Sampling Points

No	Point	Location/Coordinates	Distance to the perimeter canal
1	1	0º49'23.57" S 100º22'54.43" E	21 M *
2	2	0º49'36.74" S 100º22'53.14" E	37 M
3	3	0º49'34.84" S 100º22'50.83" E	12 M
4	4	0º49'33.11" S 100º22'46.32" E	15 M
5	5	0º49'31.54" S 100º22'44.50" E	10 M
6	6	0º49'29.47" S 100º22'45.17" E	31 M
7	7	0º49'24.08" S 100º22'49.54" E	30 M
8	8	0º49'27.19" S 100º23'02.60" E	39 M*
9	9	0º49'30.67" S 100º23'03.96" E	25 M
10	10	0º49'38.73" S 100º22'59.11" E	38 M

Source: Primary Data

C. Data Analysis Techniques

The data analysis method employed in this study was laboratory analysis utilizing Atomic Absorption Spectrophotometry (AAS). The analysis of unconfined groundwater quality surrounding the Air Dingin Landfill was conducted at the West Sumatra Provincial Health Laboratory Centre. The tested physical and chemical parameters complied with clean water quality standards, as detailed in Table 3.

Table 3. Clean Water Quality Standards

No	Parameter	Unit	Quality Standard	Method Specification
A	Physical			
1	Odor	-		
2	Taste	-		
3	Temperature	ºC	Ambient Air Temperature ±3ºC	Thermometer
4	Color	Skl TCU	50	SNI :06-6989.3-2004
5	Total Dissolved Solids (TDS)	mg/L	1500	TDS Meter

6	Total Suspended Solids (TSS).	mg/L	50 *	SNI:06-6989.3-2004
B	Chemical			
1	pH	-	6,5-9.0	SNI:06-6989.11-2005
2	Arsenic (As)	mg/L	0,05	Strip Test
3	Cadmium (Cd)	mg/L	0,005	SNI :06-2513-1991
4	Chromium (Cr)	mg/L	0,5	SNI :06-2513-1991
5	Iron (Fe)	mg/L	1,0	WI-M-K 1BLK-SB
6	Lead (Pb)	mg/L	0,05	SNI :06-6989.3-2004
7	Manganese (Mg)	mg/L	0,5	SNI :06-6989.5-2004
8	BOD_5	mg/L	2,0 *	SNI :06-2503-1991
9	COD	mg/L	10,0 *	SNI :06-6989.15-2004

*Based on Government Regulation No.82 of 2001.

3. RESULT AND DISCUSSION

1) Physical Parameters (Odor, Taste, and Color)

According to the Indonesian Ministry of Health Regulation No. 416 of 1990, which outlines clean water quality requirements, water should be odorless, tasteless, and colorless. Research conducted on unconfined groundwater near the Air Dingin revealed that 80% of the samples met these clean water quality standards. Observations related to odor, taste, and color are presented in Table 3.

Table 3. The Result Testing of Odor, Taste, and Color towards the Unconfined Groundwater

NO	WELL	ODOR	TASTE	COLOR	REMARKS
1	1	Odorless	Tasteless	Colorless	Meet the Criteria
2	2	Odorless	Tasteless	Colorless	Meet the Criteria
3	3	Odorless	Tasteless	Colorless	Meet the Criteria
4	4	Odorless	Tasteless	Colorless	Meet the Criteria
5	5	Have an Odor	Palatable	Colorless	Fail to Meet the Criteria

6	6	Odorless	Tasteless	Colorless	Meet the Criteria
7	7	Odorless	Tasteless	Colorless	Meet the Criteria
8	8	Have an Odor	Palatable	Colorless	Fail to Meet the Criteria
9	9	Odorless	Tasteless	Colorless	Meet the Criteria
10	10	Odorless	Tasteless	Colorless	Meet the Criteria

2) Temperature

Water temperature, as specified in Minister of Health Regulation No. 416 of 1990 regarding clean water quality, is the water temperature at the sampling point, which is within ± 3ºC of the air temperature around the sampling point. The results of the water temperature test are presented in Table 4.

Table 4. Results of Unconfined Groundwater Temperature Testing

NO	WELL	VALUE	STANDART QUALITY	REMARKS
1	1	28º	± 3º C	Meet the Criteria
2	2	28º	± 3º C	Meet the Criteria
3	3	27º	± 3º C	Meet the Criteria
4	4	29º	± 3º C	Meet the Criteria
5	5	30º	± 3º C	Meet the Criteria
6	6	30º	± 3º C	Meet the Criteria
7	7	27º	± 3º C	Meet the Criteria
8	8	27º	± 3º C	Meet the Criteria
9	9	28º	± 3º C	Meet the Criteria
10	10	29º	± 3º C	Meet the Criteria

From the temperature measurements conducted, all groundwater temperatures meet the requirements and are in accordance with the Indonesian Ministry of Health Regulation, as shown in Table 4.

3) Total Dissolved Solids (TDS) and Total Suspended Solids (TSS)

According to the standards set forth in Government Regulation No. 82 of 2001 regarding Water Quality Management and Water Pollution Control, the permissible level of Total Dissolved Solids (TDS) in water should not exceed 1500 mg/L, while the acceptable limit for Total Suspended Solids (TSS) is capped at 50 mg/L. Research conducted on the free groundwater around the Air Dingin Landfill indicated that all test samples complied with the criteria for clean water quality. The findings from the TDS and TSS tests are detailed in Table 5.

Table 5. Result Testing of TDS and TSS of the Unconfined Groundwater

NO	WELL	TDS (mg / L)	TSS (mg / L)	REMARKS
1	1	77	6	Meet the Criteria
2	2	109	2	Meet the Criteria
3	3	17.4	2	Meet the Criteria
4	4	19.2	3	Meet the Criteria
5	5	13.1	2	Meet the Criteria
6	6	17.2	6	Meet the Criteria
7	7	19.1	4	Meet the Criteria
8	8	18.6	4	Meet the Criteria
9	9	12.9	3	Meet the Criteria
10	10	9.8	6	Meet the Criteria

4) Chemical Conditions

Acidity Degree (pH)

According to the Ministry of Health Regulation No. 416 of 1990 regarding clean water quality, the normal pH range of groundwater is from 6.0 to 9.5. The pH values obtained in this study indicate that 100% of the tested samples did not meet the requirements set by the Indonesian Ministry of Health Regulation, as shown in Table 6.

Table 6. Result of the Unconfined Groundwater pH Testing

No	WELL	VALUE	STANDART QUALITY	REMARKS
1	1	6.05	6.5 – 9.0	Fail to Meet the Criteria
2	2	3.04	6.5 – 9.0	Fail to Meet the Criteria
3	3	3.65	6.5 – 9.0	Fail to Meet the Criteria
4	4	4.24	6.5 – 9.0	Fail to Meet the Criteria
5	5	3.79	6.5 – 9.0	Fail to Meet the Criteria
6	6	3.8	6.5 – 9.0	Fail to Meet the Criteria
7	7	5.7	6.5 – 9.0	Fail to Meet the Criteria
8	8	5.5	6.5 – 9.0	Fail to Meet the Criteria

9	9	4.9	6.5 – 9.0	Fail to Meet the Criteria
10	10	5.1	6.5 – 9.0	Fail to Meet the Criteria

The ambient pH (leachate, soil, or groundwater) surrounding the ultimate disposal site (TPA) is in the very acidic range, approximately 3–5, according to the research findings (Table 6). This suggests extremely ideal conditions for heavy metals like Pb, Cd, Cu, and Zn to dissolve and move. Because soil sorption and the precipitation of metal hydroxides or carbonates both decrease at low pH (Maneesha et al., 2019). Consequently, these metals are more readily discharged into surface runoff or groundwater from the landfill. The food chain may then be contaminated by these metals (for instance, through vegetables produced close to the landfill or inhabitants' well water). Residents in the area may be more susceptible to long-term consequences, such as kidney disease and neurodevelopmental issues in children.

Heavy metal content (Arsenic, Cadmium, Chromium, Ferum, Lead, and Manganese)

In accordance with the standards established by the Minister of Health Regulation No. 416 of 1990 regarding clean water quality, the levels of arsenic present in clean water are detailed in Table 2. The heavy metal analysis results for all samples demonstrate that their concentrations fall below the quality standards set forth by the Indonesian Minister of Health Regulation, as illustrated in Table 7 (Triawan, 2020).

Table 7. Results of Arsenic Testing in Unconfined Groundwater

No	Well	Unit	As	Cd	Cr	Fe	Pb	Mn	Remarks
1	1	mg/L	<0.005	<0.002	<0.002	0.410	<0.003	0.258	Meet the Criteria
2	2	mg/L	<0.005	<0.002	<0.002	0.320	<0.003	<0.089	Meet the Criteria
3	3	mg/L	<0.005	<0.002	<0.002	<0.003	<0.003	<0.090	Meet the Criteria
4	4	mg/L	<0.005	<0,002	<0,002	<0.003	<0,003	<0.026	Meet the Criteria
5	5	mg/L	<0.005	<0.002	<0.002	<0.993	<0.003	0.041	Meet the Criteria
6	6	mg/L	<0.005	<0.002	<0.002	0.31	<0.003	0.024	Meet the Criteria
7	7	mg/L	<0.005	<0.002	<0.002	0.42	<0.003	0.022	Meet the Criteria
8	8	mg/L	<0.005	<0.002	<0.002	<0.003	<0.003	0.033	Meet the Criteria
9	9	mg/L	<0.005	<0.002	<0.002	0.26	<0.003	0.029	Meet the Criteria
10	10	mg/L	<0.005	<0.002	<0.002	<0.003	<0.003	0.026	Meet the Criteria

Table 7 shows that heavy metal levels around the landfill have not exceeded safe limits. If this condition can be maintained, residents living near the landfill will be protected from heavy metal contamination through water and vegetation (Lindamulla L 2022) . Figure 3 provides a clearer comparison.

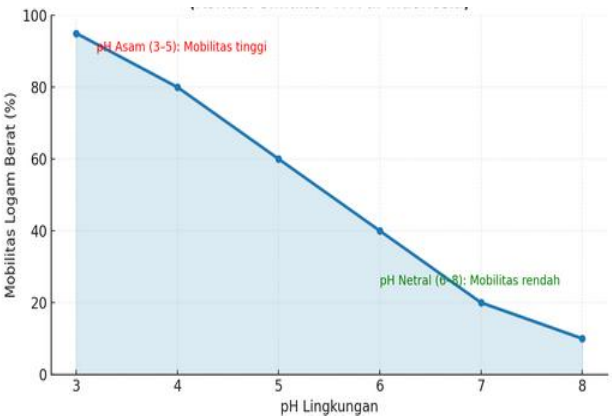

Figure 3. Relationship between heavy metal mobility and pH (in the context of landfill simulation conditions in Indonesia)

Biological Oxygen Demand (BOD), dan Chemical Oxygen Demand (COD)

According to Government Regulation No. 82 of 2001 regarding Class 1 clean water quality, the maximum allowable levels for Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) in clean water are set at 2 mg/L. Laboratory analyses of unconfined groundwater surrounding the Air Dingin Landfill reveal that 90% of the samples tested fall below the threshold established by the government. The specific BOD and COD levels are detailed in Table 8.

Table 8. Results of BOD and COD testing on the Unconfined Groundwater

No	WELL	BOD (mg/L)	COD (mg/L)	REMARKS
1	1	2.5	11.31	Fail to Meet the Criteria
2	2	1.2	5.65	Meet the Criteria
3	3	1.2	8.48	Meet the Criteria
4	4	1.7	8.48	Meet the Criteria
5	5	1.2	5.65	Meet the Criteria
6	6	1.2	8.20	Meet the Criteria
7	7	1.4	7.60	Meet the Criteria
8	8	1.2	9.40	Meet the Criteria
9	9	1.3	7.90	Meet the Criteria
10	10	1.6	5.60	Meet the Criteria

The increasing volume of waste deposited at the Air Dingin Landfill will lead to a rise in leachate production. It is essential to manage the leachate generated from the waste piles to prevent it from seeping into undesired areas. The Open Dumping waste management system employed at the Air Dingin Landfill requires the landfill manager to establish an effective leachate drainage system. With the onset of the rainy season, leachate production is anticipated to surge; therefore, the drainage channel must be capable of handling all leachate generated from the waste piles. At the Air Dingin Landfill, the leachate drainage channel is constructed entirely around the waste pile. This design ensures that all leachate that exits laterally can be effectively controlled and directed into the leachate control pond. Some of the leachate may infiltrate the ground vertically. This leachate penetrates the soil and can lead to groundwater pollution. (Heny Purwanti, 2014).

The research findings regarding the condition of unconfined groundwater around the Air Dingin Landfill indicate that the physical parameters specifically odor, taste, temperature, total dissolved solids (TDS), and total suspended solids (TSS)—generally remain below the quality standards set forth in the Indonesian Minister of Health Regulation No. 416 of 1990 and Government Regulation No. 82 of 2001. Notably, variations in the odor and taste parameters were observed only in test wells No. 5 and No. 8, where the free groundwater exhibited no discernible odor or taste. This may be attributed to well No. 5's proximity to the pollution source (just ten meters away) and the presence of water algae in the well. Conversely, well No. 8 is situated thirty-nine meters from the landfill but is near a broiler chicken coop.

The research findings on the condition of unconfined groundwater surrounding the Air Dingin Landfill indicate that the concentrations of chemical elements such as Arsenic, Cadmium, Chromium, Iron, Lead, Manganese, BOD, and COD generally fall below the quality standards established by Minister of Health Regulation No. 416 of 1990 and Government Regulation No. 82 of 2001. Taufik Ashar et al. (2013) further noted that their analysis revealed no correlation between the distance of dug wells from the landfill and the concentrations of chromium, lead, or mercury in the wells' water. It aligns with previous studies that examined the relationship between the distance of dug wells from the landfill and the concentration of cadmium in community well water within the same area (Azhar T. et al., 2011).

In the context of the study conducted on groundwater quality near the Air Dingin Landfill, distinct conditions were explicitly observed in Test Well No. 1. It was found that the Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) values in this well exceeded the standards established by Government Regulation No. 82 of 2001. This anomaly is potentially attributable to the well's proximity to a leachate treatment pond, which contains organic materials characterized by a low rate of decomposition (Wa Atima, 2015).

The test findings for the chemical elements of the Degree of Acidity (pH) of Free Groundwater for all experimental wells do not meet the requirements set by the Government, namely the Regulation of the Minister of Health of the Republic of Indonesia No. 416 of 1990 where all the results of the Degree of Acidity (pH) test are below 6.0 (acidity). It may be because, in the initial stage, many organic compounds with small molecular weights are found; however, the fraction of compounds with high molecular weights that are slow to decompose also decreases. Overall, the DO (Dissolved Oxygen Demand) and BOD (Biological Oxygen Demand) from NH3-N contained in leachate will experience changes over time. BOD decreases faster than COD, because BOD is composed of organic substances that are readily decomposed by various bacteria in the landfill, producing H+ ions that will lower the pH (Purwanti, 2014). It means that for new landfills, less than 5 years old, biological processing will be efficient. However, over time, the leachate quality will become more suitable for physical and chemical processing (Almeisa, 2024).

The soil composition surrounding the Air Dingin Landfill is clayey. Clay exhibits low porosity due to its fine and dense grain structure, which contrasts with that of sandy soils. This particular soil characteristic plays a crucial role in impeding the infiltration of leachate into the subsurface environment, thereby mitigating its potential impact on groundwater resources.

A study conducted by the United States Environmental Protection Agency (USEPA) in 2003 indicated that the movement velocity of leachate through soil matrices is influenced by several factors, including the specific chemical constituents, soil type, porosity, precipitation levels, and the hydrological gradient of the soil. For example, the travel rate of iron compounds in the soil is reported to vary between 0.15 mm/min and 2.5 mm/min, whereas sulfate compounds demonstrate a velocity range of 0.02 mm/min to 2.0 mm/min.

4. CONCLUSION

Based on the research findings, the conclusions are as follows: The quality of unconfined groundwater surrounding the Air Dingin Landfill complies with the standards outlined in Minister of Health Regulation No. 416 of 1990 and Government Regulation No. 82 of 2001. Laboratory analysis of ten samples indicated that only samples 5 and 8 exhibited any noticeable odor and taste, while sample one showed biochemical oxygen demand (BOD) and chemical oxygen demand (COD) values slightly exceeding the required quality standards. Additionally, All samples showed pH values ranging from 3.04 to 6.05, which is below the permissible limit (6.5–9.0). Overall, leachate from the waste piles did not have a significant impact on the physical and chemical parameters of free groundwater around the Air Dingin TPA, where the heavy metal content of Pb, Cd, Cu, As, Cr, and Fe was below the permitted threshold.

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