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Analysis of NH₃ Distribution and Community Perception of Odor in the Antang Landfill Area, Makassar City

Qurin Septifar Aulia^{ID}, Muhammad Isran Ramli^{ID} and Sumarni Hamid Aly^{†ID}

Department of Environmental Engineering, Faculty of Engineering, Hasanuddin University, Makassar, Indonesia

[†]Corresponding author: Sumarni Hamid Aly; marnihamidaly@yahoo.com**ARTICLE HISTORY**

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Open Access under CC BY 4.0.**PUBLISHED BY****ABSTRACT**

This study analyzes ammonia (NH₃) concentrations, spatial distribution, and community perceptions of odor around the Antang Landfill (TPA Antang) in Makassar, Indonesia. NH₃ measurements were conducted using the impinger method at five sampling points based on distance and the dominant wind direction, with spatial visualization performed using inverse distance weighting (IDW) interpolation in ArcGIS. Community perceptions were assessed through questionnaires administered to 100 respondents living within a radius of 20–1,000 m from the landfill. The results showed that the highest NH₃ concentration occurred at Point 3 (landfill area), reaching 5.885 ppm at night, exceeding the national odor threshold of 2 ppm. The spatial distribution indicated dominant dispersion from southeast to northwest, consistent with the prevailing wind direction. Approximately 67% of respondents reported odor disturbances, and 63% reported health-related symptoms such as headaches, nausea, and shortness of breath. The findings highlight the urgent need for improved landfill management and odor control strategies.

1. INTRODUCTION

Rapid urbanization, population growth, and increasing consumption patterns have become major drivers of municipal solid waste generation in developing cities worldwide, particularly in Southeast Asia (Imran 2024, World Bank 2018, WHO 2018). Urban centers experiencing accelerated economic growth often have waste generation rates that exceed the capacity of existing waste management infrastructure, leading to environmental degradation and heightened public health risks (Hoorweg & Bhada-Tata 2012, Kaza et al. 2018). In many developing countries, including Indonesia, landfill-based disposal remains the dominant waste management strategy, with a large proportion of facilities still operating under open dumping systems that lack adequate environmental safeguards (Putri et al. 2020, World Bank 2018).

Makassar City, one of the fastest-growing metropolitan areas in Eastern Indonesia, exemplifies these challenges. All municipal solid waste generated in the city is disposed of at the Antang landfill, which continues to operate using an open dumping method. This practice facilitates uncontrolled aerobic and anaerobic decomposition of organic waste, resulting in the release of various gaseous pollutants into the surrounding atmosphere (U.S. EPA 2017, Le Cloirec et al. 2012). Among these emissions, ammonia (NH₃) has been identified as one of the most significant pollutants due to its high volatility, strong odor, and potential

adverse effects on environmental quality and human health (ATSDR 2004, Fang et al. 2017).

Previous studies conducted in Makassar have highlighted the presence of ammonia (NH_3) as an important air pollutant in urban environments. Ramli et al. (2023) reported measurable ambient NH_3 concentrations associated with anthropogenic activities, indicating that NH_3 contributes to localized air quality degradation and odor-related disturbances. These findings underscore the importance of investigating NH_3 emissions originating from municipal solid waste disposal sites, such as landfills, where organic waste decomposition constitutes a major source of NH_3 release into the atmosphere. Ammonia is primarily generated through the microbial degradation of nitrogen-rich organic materials, including food waste and animal residues commonly present in municipal solid waste streams (McGinn et al. 2007, Seinfeld & Pandis 2016). Even at relatively low ambient concentrations, NH_3 can cause irritation of the eyes, skin, and respiratory tract, reduce overall environmental comfort, and trigger odor nuisance complaints among nearby residents (Sutrisno 2011, Kim & Park 2008, WHO 2018). Moreover, NH_3 plays a crucial role in secondary particulate matter formation through atmospheric reactions with acidic compounds, thereby indirectly contributing to broader air quality degradation (Behera et al. 2013, Seinfeld & Pandis 2016).

The dispersion and spatial distribution of NH_3 emissions from landfill sites are strongly influenced by local meteorological conditions, including air temperature, humidity, wind speed, wind direction, and atmospheric stability (Maulidah et al. 2021, Rizki et al. 2020, Duan et al. 2014). Elevated temperatures tend to enhance NH_3 volatilization, while wind characteristics determine both the direction and extent of pollutant transport (Sarkar et al. 2003, Nascimento et al. 2014). International studies have demonstrated that NH_3 plumes originating from landfill and waste treatment facilities can affect residential areas located more than one kilometer away from the emission source under favorable meteorological conditions (Duan et al. 2014, Fang et al. 2017, Nascimento et al. 2014).

Despite the recognized importance of spatial variability in air pollutant exposure, many landfill-related air quality assessments continue to rely on limited point-based measurements that are insufficient to capture the full extent of pollutant dispersion (Mohan & Kandya 2015, Wang et al. 2019). To address this limitation, geospatial approaches using Geographic Information Systems (GIS) and spatial interpolation techniques have been increasingly applied to visualize air pollution patterns and identify high-risk exposure zones (Jerrett et al. 2005, Wang et al. 2019).

Among these techniques, inverse distance weighting (IDW) has been widely used due to its simplicity, transparency, and suitability for datasets with limited sampling density, making it particularly relevant for environmental monitoring in developing regions (Li & Heap 2014, Wang et al. 2019). However, the application of IDW-based spatial mapping specifically to NH_3 emissions around landfill sites remains limited, especially in rapidly urbanizing cities such as Makassar.

In addition to physical and chemical measurements, odor nuisance represents a critical yet often underrepresented dimension of environmental pollution. Odor exposure has been shown to affect not only physical health but also psychological well-being, stress levels, and overall quality of life (Steinheider et al. 1998, Blanes-Vidal et al. 2012). Community perceptions of odor provide valuable insights into real-world exposure conditions, as residents experience pollution continuously and subjectively beyond the temporal constraints of instrumental monitoring (Kim & Park 2008, Le Cloirec et al. 2012). Nevertheless, studies that integrate objective air quality measurements with subjective community perception assessments remain scarce, particularly in the context of landfill-related NH_3 emissions in developing countries (Zilfani et al. 2021, Nascimento et al. 2014).

At the Antang landfill, existing studies have largely focused on general environmental assessments or isolated pollutant measurements without incorporating spatial modeling or community-based perception analysis. This lack of integrated assessment has resulted in an incomplete understanding of NH_3 exposure risks faced by surrounding communities, thereby limiting the effectiveness of policy interventions, spatial planning decisions, and landfill management strategies (WHO 2018, U.S. EPA 2017, World Bank 2018).

Based on the environmental challenges and research gaps identified above, this study is designed to address key research questions related to ammonia (NH_3) emissions from landfill activities at the Antang landfill in Makassar City. Specifically, this research seeks to answer the following questions: (1) What are the ambient NH_3 concentration levels across different zones and distances from the emission source around the Antang landfill? (2) How are NH_3 concentrations spatially distributed based on GIS-based mapping using the inverse distance weighting (IDW) interpolation method? (3) How do local communities perceive odor exposure and environmental comfort disturbances associated with NH_3 emissions in the vicinity of the Antang landfill?

Addressing these questions is expected to provide an integrated scientific basis for improving landfill management

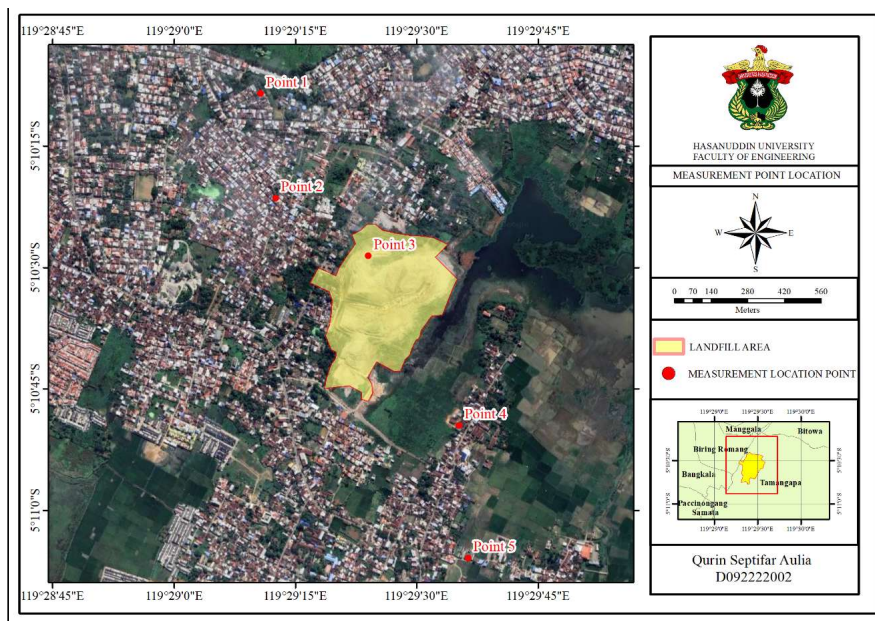


Fig. 1: Map of the research location.

practices, supporting risk-based spatial planning, and informing evidence-based air pollution mitigation strategies in Makassar City.

2. MATERIALS AND METHODS

2.1. Study Area

The Antang Tamangapa landfill serves as the primary waste management facility for Makassar City. Situated in Tamangapa Village within Manggala District, it spans approximately 14.3 ha. Surrounded by residential areas and plantations, the landfill has been operational since 1994 and receives waste from 14 subdistricts, making it the largest disposal site in Makassar. The research was conducted in February 2025, during which NH_3 levels were measured at selected points around the landfill. The specific locations of the sampling sites are shown in Fig. 1.

2.2. Collection Techniques

The data collection process in this study was conducted through several stages, including:

2.2.1. Determination of Sampling Locations

The study was conducted at five sampling points surrounding the Tamangapa Landfill. Point 1 was situated 1,000 m northwest, Point 2 at 500 m northwest, Point 3 just 20 m from the landfill, Point 4 at 500 m southeast, and Point 5 at 1,000 m southeast. Sampling locations were selected based on the Indonesian National Standard SNI 19-71196-2005

for ambient air quality monitoring. The criteria included areas with high pollutant levels, high population density, zones surrounding the research site, and projection areas that accurately reflect the entire study area. The prevailing wind direction during the study period is illustrated in Fig. 2.

2.2.2. NH_3 Sampling Procedure

Air sampling was carried out in February 2025 at five designated points. Measurements occurred during four distinct periods, morning, midday, afternoon, and night, with each session lasting 1 h. Each sampling point and time period was sampled once. NH_3 levels were measured using a manual impinger method at the same four intervals, following the Regulation of the Ministry of Environment and Forestry

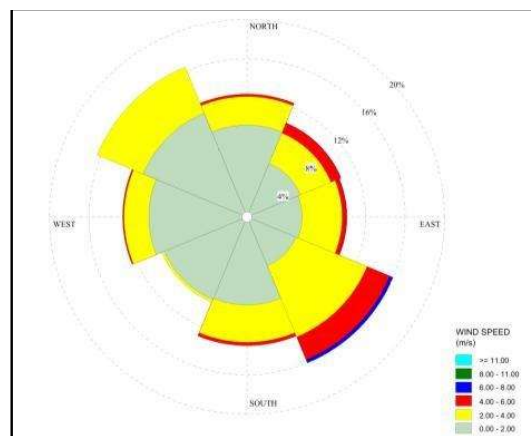


Fig. 2: Wind rose for the monitoring area.



Fig. 3: Impinger used for NH_3 sampling.

(Permen LHK) No. 27/2021. All procedures adhered to the Indonesian National Standard SNI 19-71196-2005. The equipment used in this study is illustrated in Fig. 3.

NH_3 sampling took place on five separate days during the rainy season in February. At each sampling location, data were collected across four distinct time periods, morning (06:00–10:00), midday (10:00–14:00), afternoon (14:00–18:00), and night (18:00–22:00), to capture diurnal variations. During each period, active sampling was conducted for 1 h. This sampling approach complied with the Regulation of the Indonesian Minister of Environment No. 12 of 2010, ensuring that measurements reflected different atmospheric conditions and landfill activity levels throughout the day. To ensure data accuracy and capture diurnal patterns, measurements at each point were replicated across all four

Table 1: Geographic coordinates and sampling schedule for NH_3 monitoring in the Antang Landfill area.

Point	Distance and Direction from Source	Coordinate Point		Sampling Date (2025)
		X	Y	
1	1,000 m northwest	-5.1703023	119.4864544	7 February 2025
2	500 m northwest	-5.1733633	119.4861909	10 February 2025
3	Inside Landfill (Source)	-5.1737923	119.4901854	12 February 2025
4	500 m Southeast	-5.1810248	119.4928253	14 February 2025
5	1,000 m southeast	-5.1854540	119.4929906	14 February 2025

Table 2: Meteorological data summary.

Location Point	Point	Meteorological Data	Interval			
			Morning	Midday	Afternoon	Night
1	Located 1,000 m northwest of the landfill site	Temperature ($^{\circ}\text{C}$)	30	31	30	29
		Relative Humidity (%)	86	74	78	75
		Atmospheric pressure (mmHg)	759.03	757.54	758.04	758.11
		Wind speed (m s^{-1})	1.1	0.85	0.9	1.05
2	Located 500 m northwest of the landfill site	Temperature ($^{\circ}\text{C}$)	29	30	33	29
		Relative humidity (%)	85	77	73	84
		Atmospheric pressure (mmHg)	759.1	758.2	757.02	759.03
		Wind speed (m s^{-1})	2.05	1.45	1.33	1.35
3	Landfill site point	Temperature ($^{\circ}\text{C}$)	30	33	28	28
		Relative humidity (%)	81	79	83	81
		Atmospheric pressure (mmHg)	758.04	757.84	759.42	759.08
		Wind speed (m s^{-1})	1.08	1.05	1.65	1.55
4	Located 500 m southeast of the landfill site	Temperature ($^{\circ}\text{C}$)	30	32	30	29
		Relative humidity (%)	82	81	82	84
		Atmospheric pressure (mmHg)	758.01	757.05	758.81	759.08
		Wind speed (m s^{-1})	2.55	3.25	2.75	2.35
5	Located 1,000 m southeast of the landfill site	Temperature ($^{\circ}\text{C}$)	29	33	32	29
		Relative humidity (%)	89	80	82	84
		Atmospheric pressure (mmHg)	759.08	757.03	758.93	759.11
		Wind speed (m s^{-1})	1.05	2.4	1.15	1.55

time intervals in accordance with national monitoring standards. The sampling coordinates and schedule are presented in Table 1, and the corresponding meteorological data are summarized in Table 2.

2.2.3. Community Perception Data Collection

Community perception data were collected through the distribution of structured questionnaires. The questionnaire instrument was developed based on previous studies. The study population comprised all households in Antang Subdistrict (18,533 households) and Tamangapa Subdistrict (17,845 households), resulting in a total population of 36,378 households. To determine a representative sample size, Slovin's formula was applied with a margin of error (d) set at

0.1. Based on this calculation, a sample size of 99.7 households was obtained and subsequently rounded up to 100 respondents for the community perception survey. The respondents were evenly distributed across two residential radius zones (≤ 500 m and >500 –1,000 m). Each household was represented by one respondent of productive age (15–64 years) who resided in the vicinity of the landfill, thereby ensuring relevant representation of community perceptions regarding local environmental conditions. Responses to the odor disturbance question were initially measured using a four-point Likert scale (strongly agree, agree, disagree, and strongly disagree). For statistical analysis, the responses were grouped into two categories: “disturbed” (strongly agree and agree) and “not disturbed” (disagree and strongly disagree). A chi-square test was used

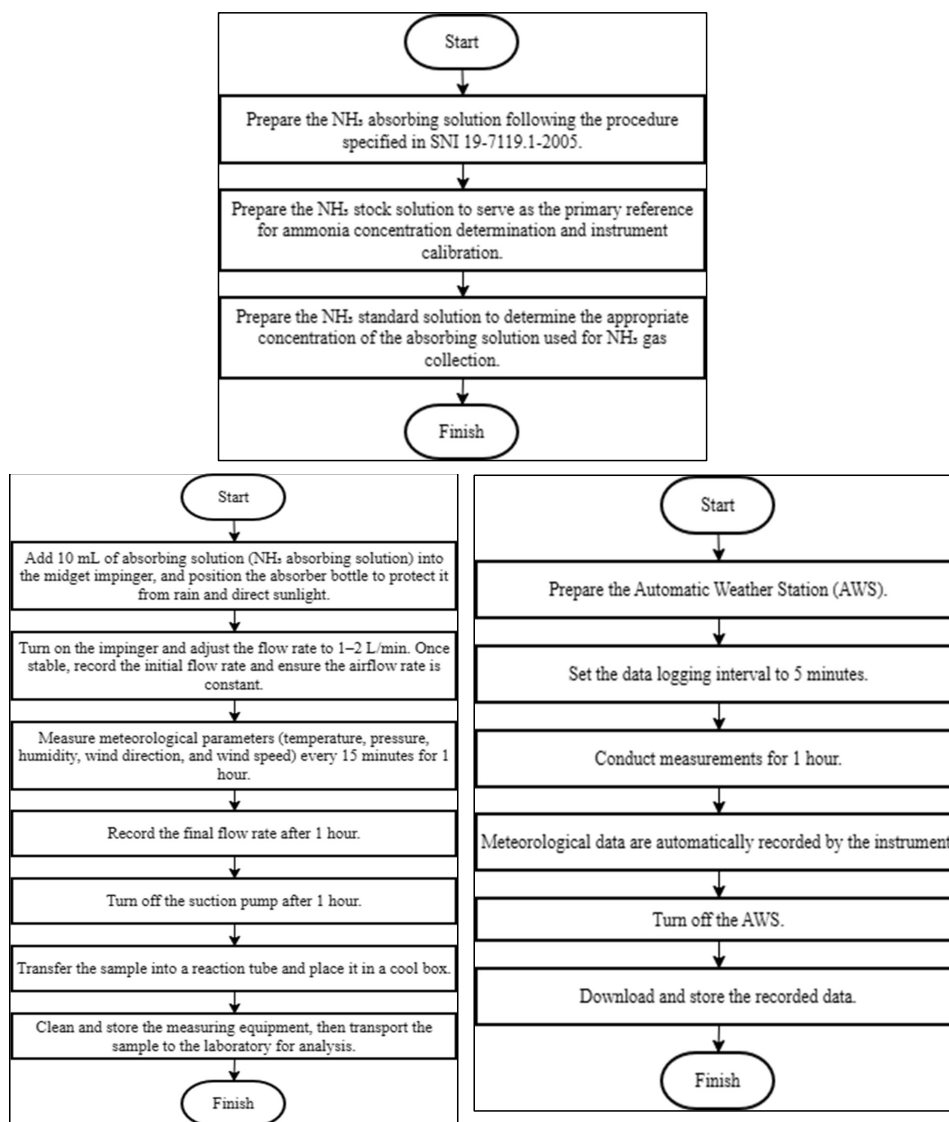


Fig. 4: Diagram of NH_3 pollutant data processing.

to examine the association between respondent characteristics and perceptions of odor disturbance.

2.2.4. Ethical Considerations

This study adhered to fundamental ethical research principles involving human participants. Prior to data collection, respondents were provided with a clear explanation of the study objectives, procedures, and intended use of the data. Participation was entirely voluntary, and informed consent was obtained from all respondents before the questionnaire was administered. Participants were assured that their responses would remain anonymous and confidential and that the collected data would be used exclusively for academic and research purposes. Furthermore, respondents were informed of their right to decline participation or withdraw from the study at any stage without any penalty or consequences.

2.3. Data Analysis

Data analysis involved the use of Excel for concentration calculations and questionnaire data processing, while ArcGIS was used for visualization. The NH₃ data-processing workflow is illustrated in Fig. 4.

2.3.1. NH₃ Data Analysis

2.3.2. Visualization of NH₃ Gas Distribution

After determining the average concentration values obtained at each sampling point, a spatial visualization of NH₃ gas distribution was generated using the inverse distance weighting (IDW) interpolation method in ArcGIS. The visualization workflow is shown in Fig. 5, and the resulting spatial distribution map is presented in Fig. 11.

The determination of interval classes was preceded by defining the number of classes used to group the data. Therefore, selecting an appropriate number of classes is a crucial step in data mapping. The number of classes was determined using Sturges' formula, as expressed in Equation (1).

$$K = 1 + 3.3 \log n \quad \dots(1)$$

Where:

K = number of classes,

n = number of data sets.

2.3.3. Questionnaire Data Analysis

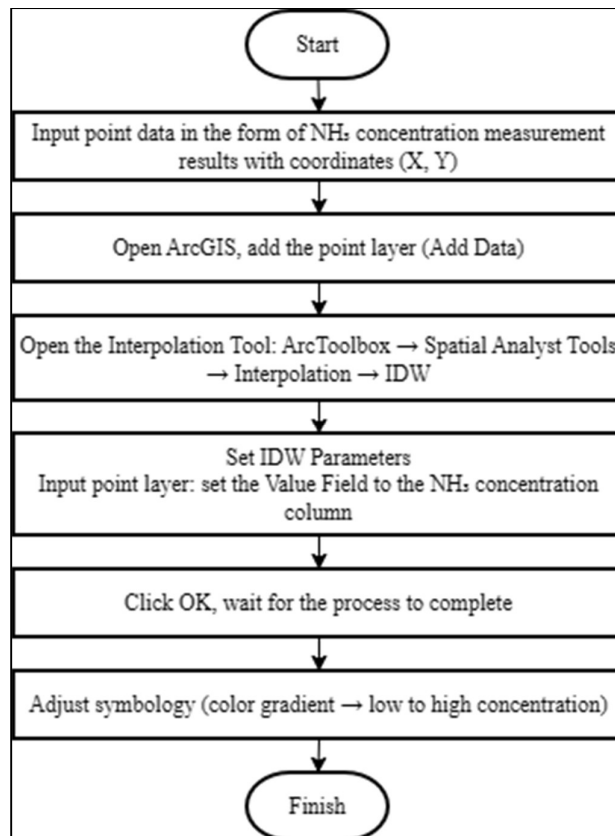


Fig. 5: NH₃ distribution visualization flowchart.

The percentage of questionnaires can be calculated using the following formula:

$$P = \frac{F}{n} \times 100\% \quad \dots(2)$$

Note:

- P = percentage (%)
- F = frequency of responses
- n = total number of respondents

The percentage formula is used to express the frequency of responses as a percentage of the total number of respondents.

3. RESULTS AND DISCUSSION

3.1. NH₃ Concentration

The NH₃ concentration was determined by collecting samples hourly over four periods: morning, midday, afternoon, and night. These ambient air samples, collected using an impinger air sampler, were analyzed in the laboratory to determine concentrations in ppm. The results for Point 1 are shown in Fig. 6. To assess regulatory compliance, the measured NH₃ levels were compared with the national odor standard. According to the Minister of Environment Decree No. 50 of 1996, the permissible ammonia limit is 2 ppm. For

comparison with mass-based concentrations, the measured NH₃ concentrations were converted from ppm to µg m⁻³ using the ideal gas relationship at the reference conditions of 25°C and 1 atm (760 mmHg). Under these conditions, 1 ppm NH₃ is approximately equivalent to 697 µg m⁻³, and the regulatory limit of 2 ppm is approximately equivalent to 1,394 µg m⁻³. Each data point represents a 1 h average, consistent with the sampling protocol. The complete measurement data across all sampling points and time periods are presented in Table 3

3.1.1. NH₃ Concentration at Sampling Point 1

Based on the direct measurement results of ammonia (NH₃) concentration at Point 1, located 1,000 m northwest of the source (landfill site), sampling was conducted for 1 h at each time interval (morning, midday, afternoon, and night). All measured concentrations remained below the ammonia odor threshold of 2 ppm. As stated in the Decree of the State Minister of Environment No. 50 of 1996 concerning Odor Level Quality Standards, the threshold is equivalent to approximately 1,394 µg m⁻³. The highest concentration was recorded at midday at 90.71 µg m⁻³, while the lowest was observed in the morning at 2.88 µg m⁻³. The concentrations were 2.88 µg m⁻³ (morning), 90.71 µg m⁻³ (midday), 52.55 µg m⁻³ (afternoon), and 40.49 µg m⁻³ (night), as shown in Fig. 6.

Table 3: Concentration (µg m⁻³).

Sampling Point	Interval	Concentration (µg m ⁻³)	Concentration (ppm)	Status
Point 1	Morning	2.876	0.004	Within the regulatory limit
	Midday	90.710	0.130	Within the regulatory limit
	Afternoon	52.553	0.075	Within the regulatory limit
	Night	40.486	0.058	Within the regulatory limit
Point 2	Morning	156.140	0.224	Within the regulatory limit
	Midday	130.632	0.188	Within the regulatory limit
	Afternoon	291.977	0.419	Within the regulatory limit
	Night	255.178	0.366	Within the regulatory limit
Point 3	Morning	2,108.438	3.027	Exceeds the regulatory limit
	Midday	1,663.853	2.389	Exceeds the regulatory limit
	Afternoon	1,452.921	2.086	Exceeds the regulatory limit
	Night	4,099.013	5.885	Exceeds the regulatory limit
Point 4	Morning	166.122	0.238	Within the regulatory limit
	Midday	79.099	0.114	Within the regulatory limit
	Afternoon	170.899	0.245	Within the regulatory limit
	Night	219.790	0.316	Within the regulatory limit
Point 5	Morning	2.866	0.004	Within the regulatory limit
	Midday	19.629	0.028	Within the regulatory limit
	Afternoon	36.240	0.052	Within the regulatory limit
	Night	26.447	0.038	Within the regulatory limit

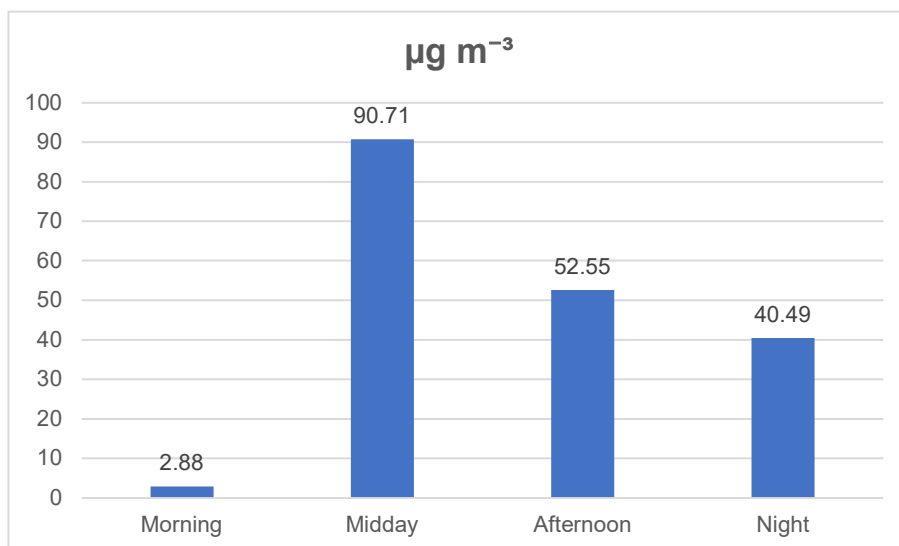


Fig. 6: Ammonia concentration at sampling point 1.

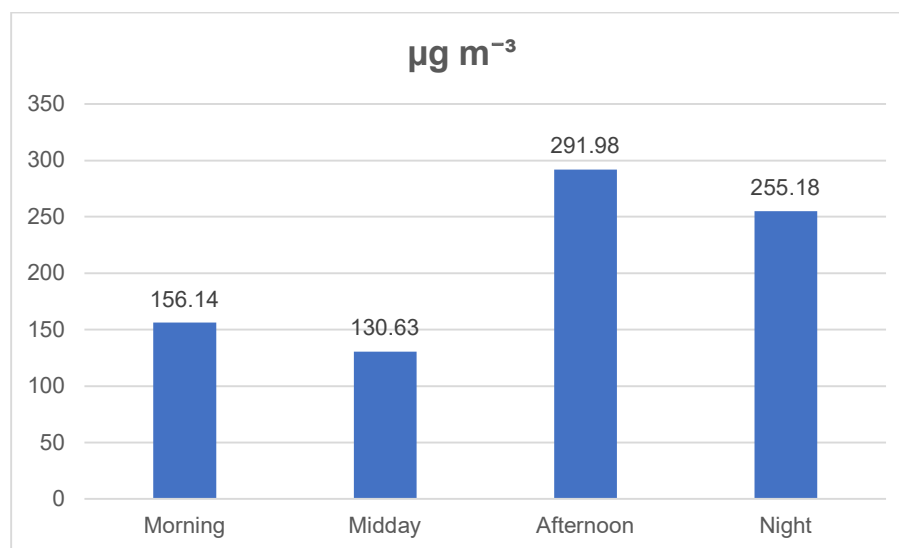


Fig. 7: Ammonia concentration at sampling point 2.

3.1.2. NH_3 Concentration at Sampling Point 2

Based on the direct measurement results of ammonia (NH_3) concentrations at Point 2, located 500 m northwest of the landfill site, sampling was conducted for 1 h at each time interval. The results showed fluctuations in daily concentrations. The lowest concentration was recorded at midday at $130.63 \mu\text{g m}^{-3}$, while the highest concentration occurred in the afternoon at $291.98 \mu\text{g m}^{-3}$. The concentration in the morning was $156.14 \mu\text{g m}^{-3}$, and at night it reached $255.18 \mu\text{g m}^{-3}$. This pattern suggests the accumulation of emissions and the influence of atmospheric stability conditions during the afternoon

and nighttime periods. Although variations were observed across the different time intervals, all measured values remained below the odor threshold of 2 ppm, equivalent to approximately $1,394 \mu\text{g m}^{-3}$. Therefore, the ambient NH_3 concentration at Point 2 remained below the applicable odor threshold. The temporal concentration profile is shown in Fig. 7.

3.1.3. NH_3 Concentration at Sampling Point 3

The results of ammonia (NH_3) concentration measurements at Point 3, located directly at the landfill emission source, showed higher concentrations than those at the other

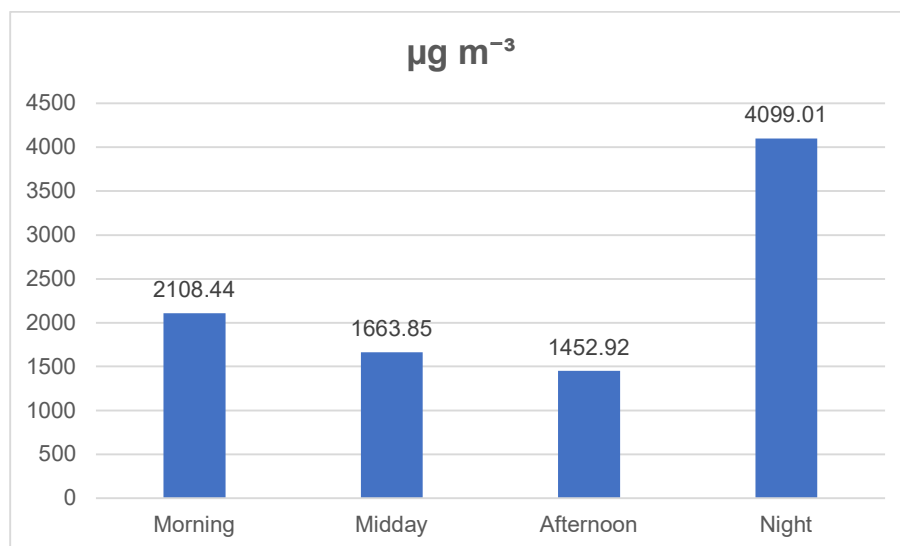


Fig. 8: Ammonia concentration at sampling point 3.

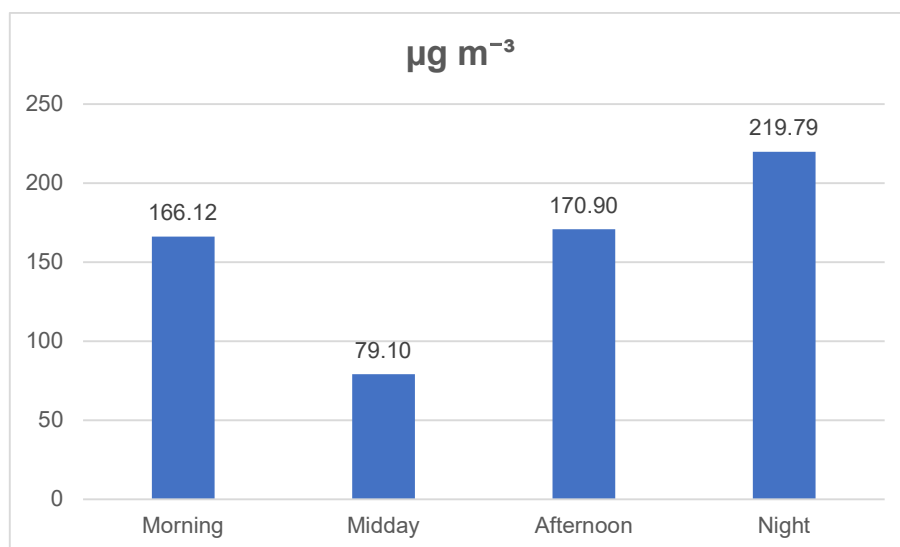


Fig. 9: Ammonia concentration at sampling point 4.

monitoring points. Measurements were conducted for 1 h during each observation interval, resulting in concentrations of $2,108.44 \mu\text{g m}^{-3}$ in the morning, $1,663.85 \mu\text{g m}^{-3}$ at midday, $1,452.92 \mu\text{g m}^{-3}$ in the afternoon, and $4,099.01 \mu\text{g m}^{-3}$ at night. All measured concentrations at Point 3 exceeded the odor threshold of $1,394 \mu\text{g m}^{-3}$ (equivalent to 2 ppm), as specified in the Decree of the State Minister of Environment No. 50 of 1996 concerning Odor Level Quality Standards. This indicates a strong potential for odor disturbance in areas located close to the landfill emission source. The highest concentration was observed during the nighttime period ($4,099.01 \mu\text{g m}^{-3}$), which may have been influenced

by atmospheric conditions such as temperature inversion and lower wind speeds, leading to the accumulation of ammonia emissions near the ground surface. In contrast, the relatively lower concentrations recorded at midday and in the afternoon may be associated with higher temperatures and stronger atmospheric mixing, which enhance the dispersion and dilution of gaseous pollutants in the atmosphere. These findings indicate that Point 3 had the highest NH_3 concentration among all monitoring points, highlighting the landfill site as the primary source of ammonia emissions in the study area. The temporal concentration profile is shown in Fig. 8.

3.1.4. NH_3 Concentration at Sampling Point 4

Based on the direct measurement results of ammonia (NH_3) concentrations at Point 4, located 500 m southeast of the landfill site, variations in concentration were observed at each time interval, indicating daily fluctuations. The

highest concentration was recorded at night at $219.79 \mu\text{g m}^{-3}$, while the lowest concentration occurred at midday at $79.10 \mu\text{g m}^{-3}$. The concentrations measured in the morning ($166.12 \mu\text{g m}^{-3}$) and afternoon ($170.90 \mu\text{g m}^{-3}$) were intermediate. This pattern shows an increase in concentration

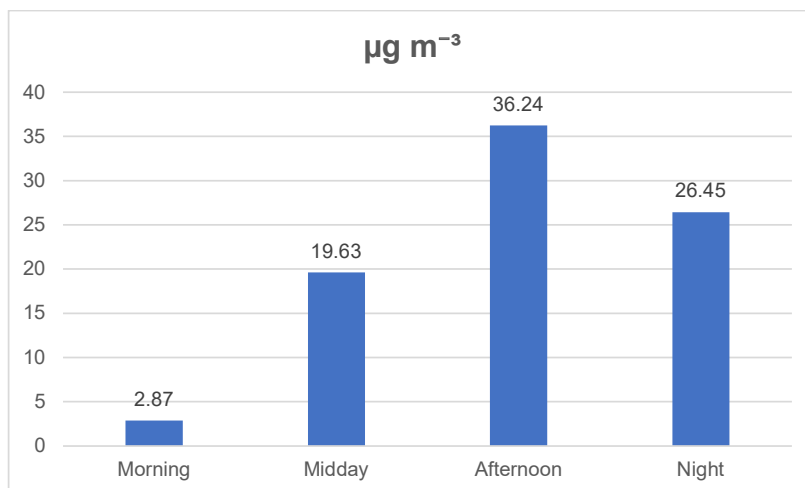


Fig. 10: Ammonia concentration at sampling point 5.

Table 4: Results of Shapiro-Wilk normality test for environmental and atmospheric parameters across all observation points.

Point	Variable	Shapiro-Wilk Statistic	df	p-value (Sig.)	Remark
1	Odor concentration	0.989	4	0.954	Normally Distributed
	Temperature	0.945	4	0.683	Normally Distributed
	Humidity	0.862	4	0.267	Normally Distributed
	Pressure	0.927	4	0.579	Normally Distributed
	Wind speed	0.911	4	0.488	Normally Distributed
2	Odor concentration	0.903	4	0.446	Normally Distributed
	Temperature	0.791	4	0.086	Normally Distributed
	Humidity	0.897	4	0.416	Normally Distributed
	Pressure	0.746	4	0.035	Normally Distributed
	Wind speed	0.751	4	0.04	Normally Distributed
3	Odor concentration	0.816	4	0.133	Normally Distributed
	Temperature	0.848	4	0.22	Normally Distributed
	Humidity	0.963	4	0.798	Normally Distributed
	Pressure	0.988	4	0.948	Normally Distributed
	Wind speed	0.825	4	0.155	Normally Distributed
4	Odor concentration	0.928	4	0.58	Normally Distributed
	Temperature	0.895	4	0.406	Normally Distributed
	Humidity	0.827	4	0.161	Normally Distributed
	Pressure	0.929	4	0.59	Normally Distributed
	Wind speed	0.949	4	0.712	Normally Distributed

at night, which is likely influenced by more stable atmospheric conditions that promote gas accumulation near the ground surface. Nevertheless, all recorded concentrations remained below the odor threshold of 2 ppm, equivalent to approximately $1,394 \mu\text{g m}^{-3}$. The temporal concentration profile is shown in Fig. 9.

3.1.5. NH_3 Concentration at Sampling Point 5

Direct NH_3 measurements conducted over a 1 h observation period 1,000 m southeast of the landfill (Point 5) demonstrated distinct temporal variations. The recorded concentrations were $2.87 \mu\text{g m}^{-3}$ in the morning, $19.63 \mu\text{g m}^{-3}$ at midday, $36.24 \mu\text{g m}^{-3}$ in the afternoon, and $26.45 \mu\text{g m}^{-3}$ at night. The peak concentration observed in the afternoon is likely attributable to elevated ambient temperatures, which enhance ammonia volatilization from decomposing organic waste. Increased landfill operational activities during the daytime may have further contributed to higher emissions. The relatively elevated nighttime concentration may be associated with more stable atmospheric conditions that reduce vertical mixing and limit pollutant dispersion. In contrast, the lowest concentration recorded in the morning may reflect lower temperatures and more favorable atmospheric mixing conditions. The temporal concentration profile is shown in Fig. 10.

The results of the normality assessment using the Shapiro-Wilk test are presented in Table 4. The Shapiro-Wilk test was selected because it is suitable for assessing normality in small samples ($N < 50$). Variables across the observation points, including odor concentration, temperature, humidity, pressure, and wind speed, were assessed for normality, and the results are presented in Table 4. The suitability of the data for parametric correlation analysis should be interpreted in accordance with the verified Shapiro-Wilk results before applying the Pearson correlation test presented in Table 5.

3.2. Visualization of NH_3 Concentration Distribution

The measured NH_3 concentrations showed spatial variability across the five sampling points. The highest hourly concentration was recorded at Point 3 during nighttime (5.885 ppm), exceeding the regulatory limit of 2 ppm for a 1 h average concentration. In contrast, the other sampling points remained within the permissible limit throughout the monitoring period. In mass concentration units, the maximum value corresponds to $4,099.013 \mu\text{g m}^{-3}$, which is higher than the equivalent regulatory threshold of $1,394 \mu\text{g m}^{-3}$ (25°C , 1 atm). The consistently elevated concentrations observed at Point 3 during all monitoring intervals suggest the presence of a local emission source associated with landfill activities.

Table 5: Pearson correlation analysis between atmospheric variables and odor concentration across observation points.

Point	Variable	r	p-value	Interpretation
T1	Temperature	0.566	0.434	Moderate positive correlation
	Humidity	-0.86	0.14	Strong negative correlation
	Pressure	-0.976*	0.024	Significant negative correlation
	Wind speed	-0.919	0.081	Strong negative correlation
T2	Temperature	0.867	0.133	Very strong positive correlation
	Humidity	-0.994*	0.006	Significant negative correlation
	Pressure	-0.968*	0.032	Significant negative correlation
	Wind speed	-0.65	0.35	Strong negative correlation
T3	Temperature	-0.441	0.559	Moderate negative correlation
	Humidity	-0.071	0.929	Very weak negative correlation
	Pressure	0.271	0.729	Weak positive correlation
	Wind speed	0.31	0.69	Weak positive correlation
T4	Temperature	0.915	0.085	Very strong positive correlation
	Humidity	-0.998	0.002	Significant negative correlation
	Pressure	-0.84	0.16	Strong negative correlation
	Wind speed	0.901	0.099	Very strong positive correlation
T5	Temperature	0.628	0.372	Strong positive correlation
	Humidity	-0.911	0.089	Very strong negative correlation
	Pressure	-0.711	0.289	Strong negative correlation
	Wind speed	0.873	0.127	Very strong positive correlation

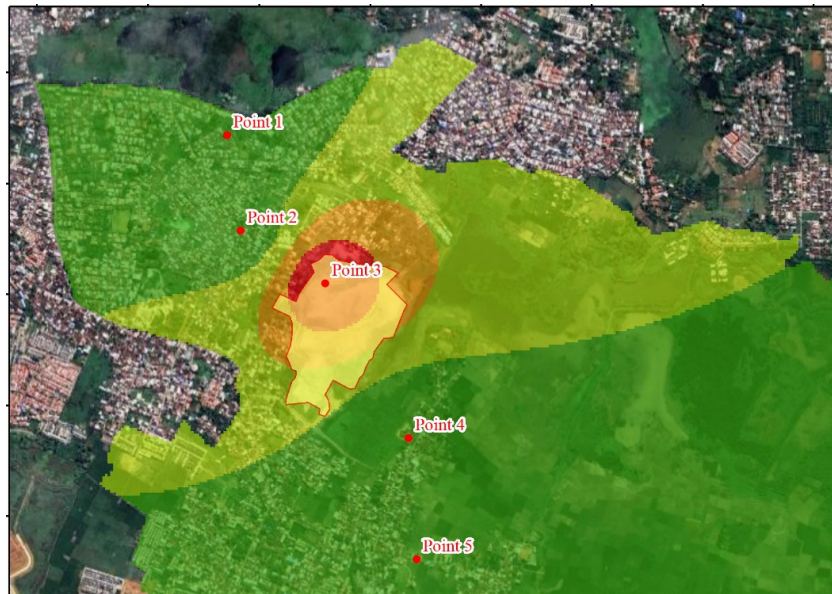


Fig. 11: Visualization of NH_3 distribution patterns at the Antang Landfill.

Table 6: Association between respondent characteristics and community perception of odor disturbance from the landfill.

Variable	Category	Disturbed n (%)	Not Disturbed n (%)	Total	p-value
Distance & Direction	20 m	15 (71.4)	6 (28.6)	21	0.009
	500 m Southeast	15 (78.9)	4 (21.1)	19	
	1 km Southeast	16 (80.0)	4 (20.0)	20	
	500 m West	6 (30.0)	14 (70.0)	20	
	1 km West	14 (70.0)	6 (30.0)	20	
Gender	Male	35 (67.3)	17 (32.7)	52	0.695
	Female	30 (62.5)	18 (37.5)	48	
Age	<20 years	4 (50.0)	4 (50.0)	8	0.077
	20–30 years	24 (60.0)	16 (40.0)	40	
	31–40 years	22 (64.7)	12 (35.3)	34	
	41–50 years	4 (36.4)	7 (63.6)	11	
	>50 years	6 (75.0)	2 (25.0)	8	
Education	Elementary School	11 (84.6)	2 (15.4)	13	0.378
	Junior High School	10 (71.4)	4 (28.6)	14	
	Senior High School	15 (55.6)	12 (44.4)	27	
	Diploma/Bachelor	30 (66.7)	15 (33.3)	45	
	Postgraduate	2 (100)	0 (0)	2	
Occupation	Civil Servant	11 (61.1)	7 (38.9)	18	0.442
	Private Sector Employee	14 (56.0)	11 (44.0)	25	
	Entrepreneur	12 (63.2)	7 (36.8)	19	
	Housewife	6 (46.2)	7 (53.8)	13	
	Waste Picker	10 (40.0)	15 (60.0)	25	

To visualize the spatial distribution pattern, inverse distance weighting (IDW) interpolation was applied using the average NH_3 concentration at each sampling point rather than individual hourly measurements. The averaged dataset ranged from 0.031 to 3.3466 ppm, which explains the difference between the interpolated maximum value and the highest hourly concentration reported in the measurements. The data were classified into four classes using Sturges' formula, resulting in an approximate class width of 0.829 ppm. The interpolated map indicates a concentration gradient in which higher NH_3 levels appear near Point 3 and gradually decrease toward the surrounding areas. This pattern suggests that NH_3 dispersion in the study area is influenced by proximity to the landfill emission source and atmospheric dilution processes with increasing distance. However, it should be noted that the spatial interpolation was based on a limited number of monitoring points; therefore, the resulting distribution map should be interpreted as a preliminary representation of the spatial pattern rather than a precise prediction of concentration levels.

3.3. Community Perception of Odor from the Antang Landfill, Makassar City

3.3.1. Disturbance Caused by Landfill Odor

As summarized in Table 6, residential distance and orientation were identified as the only variables with a

statistically significant relationship to the perceived level of odor disturbance ($p = 0.009 < 0.05$). Spatial patterns indicate that the Southeast sector experienced the highest level of disturbance, with 31% of respondents at distances between 500 m and 1 km consistently reporting subjective complaints. Conversely, in the West sector within a 500 m radius, the highest proportion of "Strongly Disagree" responses (11%) was recorded. This suggests that localized factors, such as prevailing wind patterns and topography, may be more influential in the dispersion of odor pollutants than linear distance alone.

Demographically, individual characteristics did not show a significant influence on the perception of odor disturbance ($p > 0.05$). Analysis by gender showed a relatively even distribution of complaints, with 35% of males and 30% of females reporting disturbance. Regarding age, the productive-age group (20–40 years) provided the most critical responses, accounting for 46% of the total reported subjective complaints. Based on educational level, the majority of respondents with a diploma or bachelor's degree (30%) or a senior high school education (15%) reported disturbances, reflecting higher environmental awareness among more educated groups.

A unique phenomenon was observed within the occupation variable, particularly among the waste picker group. Despite being in a high-exposure zone, the number of

Table 7: Association between respondent characteristics and community agreement regarding odor exposure from the landfill.

Variable	Category	Disturbed n (%)	Not Disturbed n (%)	Total	p-value
Distance & Direction	20 m	13 (61.9)	8 (38.1)	21	0.35
	500 m Southeast	11 (57.9)	8 (42.1)	19	
	1 km Southeast	12 (44.4)	15 (55.6)	27	
	500 m West	10 (76.9)	3 (23.1)	13	
	1 km West	13 (65.0)	7 (35.0)	20	
Gender	Male	23 (46.9)	26 (53.1)	49	0.03
	Female	36 (70.6)	15 (29.4)	51	
Age	<20 years	0 (0.0)	1 (100.0)	1	0.31
	20–30 years	14 (56.0)	11 (44.0)	25	
	31–40 years	26 (63.4)	15 (36.6)	41	
	41–50 years	13 (50.0)	13 (50.0)	26	
	>50 years	6 (85.7)	1 (14.3)	7	
Education	Elementary School	9 (60.0)	6 (40.0)	15	0.88
	Junior High School	8 (72.7)	3 (27.3)	11	
	Senior High School	16 (55.2)	13 (44.8)	29	
	Diploma/Bachelor's Degree	28 (63.6)	16 (36.4)	44	
	Postgraduate	2 (66.7)	1 (33.3)	3	
Occupation	Civil Servant	14 (70.0)	6 (30.0)	20	0.13
	Private Sector Employee	16 (64.0)	9 (36.0)	25	
	Entrepreneur	8 (38.1)	13 (61.9)	21	
	Housewife	3 (100.0)	0 (0.0)	3	
	Waste Picker	18 (58.1)	13 (41.9)	31	

respondents who felt undisturbed (15%) exceeded those who felt disturbed (10%). This may indicate sensory adaptation or habituation, in which chronic exposure leads to a subjective decrease in olfactory sensitivity. Overall, reported physical symptoms, such as coughs or mild respiratory irritation, should be interpreted as self-reported symptoms representing a decline in environmental comfort rather than definitive causal medical diagnoses.

3.3.2. Experience of Health Disturbances (e.g., Eye Irritation, Shortness of Breath, Coughing, or Headache/Nausea)

As summarized in Table 7, residential distance and orientation were the only variables that showed a significant relationship with the frequency of self-reported health-related symptoms, such as nausea and coughing ($p = 0.014 < 0.05$). The spatial data indicate that these perceived disturbances did not decrease linearly with distance. While respondents in the immediate vicinity (20 m) reported a high level of concern (8% strongly agreeing), a notable peak of “Strongly Agree” responses (10%) was observed at 1 km west of the landfill. Conversely, respondents at 500 m west reported no significant disturbances, with 13 respondents selecting the

“Disagree” category. This suggests that the dispersion of airborne pollutants, which respondents associate with their symptoms, is highly influenced by localized wind patterns and atmospheric channeling.

Demographic characteristics, including gender, age, education, and occupation, did not show statistically significant correlations with the reporting of health symptoms ($p > 0.05$). In terms of gender, females reported a higher frequency of perceived disturbances (36% combined agreement) than males (23%), indicating a potential difference in subjective sensitivity. The 31–40 age group and those with senior high school to undergraduate education levels were the most vocal in reporting symptoms, reflecting a higher tendency to associate environmental quality with physical well-being among the productive and educated population. The occupation analysis revealed that waste pickers reported the highest level of strong agreement (13%) regarding health-related symptoms. Given their prolonged and direct exposure to the landfill environment, this group perceived themselves as the most vulnerable to respiratory and olfactory discomfort.

Table 8: Association between respondent characteristics and perceived impact of landfill odor among surrounding residents.

Variable	Category	Disturbed n (%)	Not Disturbed n (%)	Total	p-value
Distance & Direction	20 m	13 (61.9)	8 (38.1)	21	0.032
	500 m Southeast	11 (57.9)	8 (42.1)	19	
	1 km Southeast	12 (44.4)	15 (55.6)	27	
	500 m West	10 (76.9)	3 (23.1)	13	
	1 km West	13 (65.0)	7 (35.0)	20	
Gender	Male	23 (46.9)	26 (53.1)	49	0.385
	Female	36 (70.6)	15 (29.4)	51	
Age	<20 years	0 (0)	1 (100.0)	1	0.471
	20–30 years	14 (56.0)	11 (44.0)	25	
	31–40 years	26 (63.4)	15 (36.6)	41	
	41–50 years	13 (50.0)	13 (50.0)	26	
	>50 years	6 (85.7)	1 (14.3)	7	
Education	Elementary School	9 (60.0)	6 (40.0)	15	0.112
	Junior High School	8 (72.7)	3 (27.3)	11	
	Senior High School	16 (55.2)	13 (44.8)	29	
	Diploma/Bachelor	28 (63.6)	16 (36.4)	44	
	Postgraduate	2 (66.7)	1 (33.3)	3	
Occupation	Civil Servant	14 (70.0)	6 (30.0)	20	0.612
	Private Sector Employee	16 (64.0)	9 (36.0)	25	
	Entrepreneur	8 (38.1)	13 (61.9)	21	
	Housewife	3 (100.0)	0 (0)	3	
	Waste Picker	18 (58.1)	13 (41.9)	31	

However, in accordance with the reviewer's feedback, these findings must be interpreted strictly as perception-based data. The reported symptoms, such as eye irritation, coughing, or nausea, are self-reported and do not constitute clinical medical diagnoses. They serve as subjective indicators of environmental nuisance and a perceived decline in quality of life associated with the landfill's operations.

3.3.3. Existing Odor Management Measures Implemented by Relevant Authorities at the Landfill

As summarized in Table 8, the statistical analysis for Question 3 indicates that residential distance and orientation are the only factors significantly associated with the community's perception of existing odor management measures ($p = 0.032 < 0.05$). The data primarily reflects a critical viewpoint, especially in the 1 km West and 20 m zones, where most respondents believe current mitigation efforts by authorities are insufficient. Notably, the 1 km Southeast sector exhibits a more divided response (12 agree vs. 15 disagree), suggesting that perceptions of management effectiveness are heavily influenced by localized exposure levels shaped by wind patterns and spatial positioning. While demographic variables such as Gender, Age, Education, and Occupation did not show statistically significant correlations ($p > 0.05$), descriptive patterns reveal that respondents with

Diploma/Bachelor's degrees (28 respondents) and those aged 31–40 (26 respondents) are the most critical of current measures. Additionally, Waste Pickers, who face direct daily exposure, also largely agree (18 respondents) that odor control is inadequate. Consistent with the reviewer's guidance, these findings should be viewed as perception-based assessments of environmental governance. They reflect the community's dissatisfaction and the perceived gap between technical interventions and the actual reduction of environmental nuisances in their residential areas.

3.3.4. Improvement of Waste Management at the Landfill Is Needed

As summarized in Table 9, Question 4 shows a consistent perception of disturbance across all respondent categories. All respondents (100%) in every spatial and demographic category reported experiencing disturbance, while no respondents were classified as not disturbed. This pattern was observed across all distance and direction categories, including 20 m, 500 m southeast, 1 km southeast, 500 m west, and 1 km west.

Statistical analysis revealed no significant differences in reported disturbance across distance and direction ($p = 0.99$), gender ($p = 0.99$), age ($p = 0.98$), education ($p = 0.99$), or occupation ($p = 0.99$). Thus, within the study population, the

Table 9: Association between respondent characteristics and community perception indicating full agreement regarding landfill odor conditions.

Variable	Category	Disturbed n (%)	Not Disturbed n (%)	Total	p-value
Distance & Direction	20 m	21 (100.0)	0 (0.0)	21	0.99
	500 m Southeast	19 (100.0)	0 (0.0)	19	
	1 km Southeast	27 (100.0)	0 (0.0)	27	
	500 m West	13 (100.0)	0 (0.0)	13	
	1 km West	20 (100.0)	0 (0.0)	20	
Gender	Male	49 (100.0)	0 (0.0)	49	0.99
	Female	51 (100.0)	0 (0.0)	51	
Age	<20 years	1 (100.0)	0 (0.0)	1	0.98
	20–30 years	25 (100.0)	0 (0.0)	25	
	31–40 years	41 (100.0)	0 (0.0)	41	
	41–50 years	26 (100.0)	0 (0.0)	26	
	>50 years	7 (100.0)	0 (0.0)	7	
Education	Elementary School	15 (100.0)	0 (0.0)	15	0.99
	Junior High School	11 (100.0)	0 (0.0)	11	
	Senior High School	29 (100.0)	0 (0.0)	29	
	Diploma/Bachelor	44 (100.0)	0 (0.0)	44	
	Postgraduate	3 (100.0)	0 (0.0)	3	
Occupation	Civil Servant	20 (100.0)	0 (0.0)	20	0.99
	Private Sector Employee	25 (100.0)	0 (0.0)	25	
	Entrepreneur	21 (100.0)	0 (0.0)	21	

reported disturbance was consistently observed regardless of spatial location or demographic characteristics. For example, all 27 respondents in the 1 km southeast category reported disturbance, as did all respondents in the 20 m and western sectors.

The absence of respondents in the “Not Disturbed” category indicates a strong and consistent community perception of disturbance associated with the landfill environment. However, because all categories showed the same 100% proportion of disturbed respondents, the statistical tests did not identify differences between groups. These findings suggest that the perception of disturbance extends across the study area and is shared by respondents with different demographic backgrounds.

4. CONCLUSIONS

Based on the converted odor threshold limit of $1,394 \mu\text{g m}^{-3}$, exceedances were observed solely at Sampling Point 3 (landfill source) across all time intervals, while concentrations at other locations remained below the regulatory threshold. The study results indicate that the highest ammonia (NH_3) concentration in the Antang landfill area occurred prominently at Sampling Point 3, located directly within the landfill site, reaching 5.885 ppm at night, well above the ambient NH_3 standard limit of 2 ppm. Conversely, Sampling Points 1 and 5, each situated 1,000 m from the landfill, recorded the lowest ammonia levels of 0.004 ppm in the morning, remaining comfortably below the permissible standard. Visual mapping of spatial distribution shows that the highest concentrations, depicted by red and orange hues, were centered around Point 3 and dispersed northwestward, covering Point 2 (500 m) and Point 1 (1,000 m). This pattern is strongly influenced by the prevailing southeast-to-northwest wind direction. In contrast, the lowest concentrations, indicated by dark green shades, were observed in areas up to 1,000 m from the landfill, particularly toward the southeast at Points 4 and 5, demonstrating a gradual decline in pollutant levels with increasing distance from the emission source. Community perception analysis, considering gender, age, education level, occupation, and residential distance, revealed that 67% of respondents reported being disturbed by landfill odors. This disturbance was most acute among residents residing closest to the landfill and along the dominant wind path from southeast to northwest, especially within 500 m. Conversely, waste pickers reported less discomfort due to long-term habituation, despite ongoing exposure. Additionally, 63% of respondents experienced health issues such as dizziness, nausea, and shortness of breath. Most respondents also felt that odor management by authorities was ineffective, and

nearly all agreed that landfill management practices need substantial improvement.

5. POLICY IMPLICATIONS

The findings of this study highlight the importance of enhanced government oversight in managing the Antang landfill. Improved management is essential to reduce ammonia (NH_3) emissions and curb odor issues that negatively impact nearby communities. The current waste management practices are insufficient to protect environmental quality and public health, as evidenced by high NH_3 levels and frequent odor complaints. Consequently, local authorities must implement more systematic landfill operations and conduct regular NH_3 monitoring, complemented by spatial analysis to guide risk-based buffer zones and urban development plans. Incorporating community feedback into policy evaluation is also crucial to ensure that landfill strategies address both technical pollution data and residents' daily experiences.

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