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Analysis of NH_3 Distribution and Community Perception of Odor in the Antang Landfill Area, Makassar City

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Abstract : This study analyzes ammonia (NH_3) concentrations, spatial distribution, and community perceptions of odor around the Antang Landfill (TPA Antang) in MakassarIndonesia. NH_3 measurements were conducted using the impinger method at five sampling points based on distance and dominant wind direction, with spatial visualization using IDW interpolation in ArcGIS. Community perception was assessed through questionnaires administered to 100 respondents living within a radius of 20–1000 m from the landfill. Results show that the highest NH_3 concentration occurred at Point 3 (landfill area), reaching 5.885 ppm at night, exceeding the national ambient air quality standard of 2 ppm. The Spatial distribution indicated a dominant dispersion from southeast to northwest, consistent with the prevailing wind direction. Approximately 67% of respondents reported odor disturbance, and 63% experienced health 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 experience waste generation rates that exceed the capacity of existing waste management infrastructure, leading to environmental degradation and heightened public health risks (Hoornweg & 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 (NH_3) 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, 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; and (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 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 is the main waste management site for the city of Makassar, located in Tamangapa Village, Manggala District, covering an area of approximately 14.3 hectares. Bordering residential areas and plantations in the surrounding area, this landfill has been operating since 1994 and accommodates waste from 14 subdistricts, making it the largest disposal site in Makassar City. This research was conducted in February 2025, during which NH_3 measurements were carried out at selected sampling points around the landfill. The research location can be seen in Figure 1.

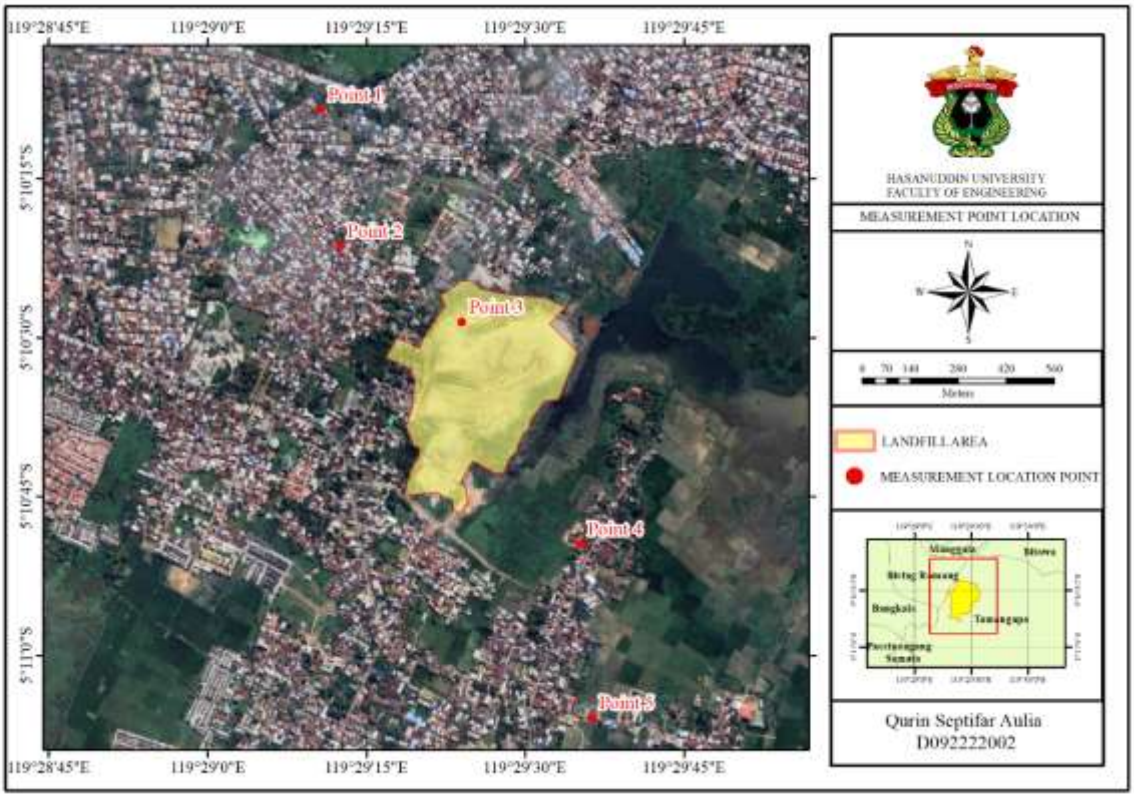


Fig 1. Map of Research Location

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 carried out at five sampling points surrounding the Tamangapa Landfill. Point 1 was located 1000 m to the northwest, Point 2 at 500 m to the northwest, Point 3 at a distance of 20 m from the landfill area, Point 4 at 500 m to the southeast, and Point 5 at 1000 m to the southeast. The selection of sampling locations was based on the Indonesian National Standard SNI 19-71196-2005 concerning the determination of ambient air quality sampling points, which includes the following criteria:(areas with high pollutant concentrations, areas with high population density, areas surrounding the study site designated as the research zone, and projection areas that adequately represent the entire study area. The dominant wind direction during the study period is presented in Figure 2.

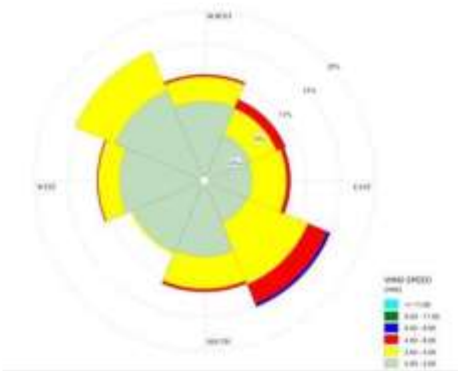


Fig 2. Windorse monitoring point

2.2.2 NH_3 Sampling Procedure

Air sampling was conducted in February 2025 at five predetermined sampling points. Measurements were performed during four time intervals (morning, afternoon, evening, and night), with each measurement lasting for 1 hour. At each sampling point and time interval, measurements were conducted once. NH_3 sampling was conducted using a manual impinger method, with measurements carried out at four time intervals, namely morning, afternoon, evening, and night, in accordance with Regulation of the Ministry of Environment and Forestry (Permen LHK) No. 27/2021. All measurement procedures followed the Indonesian National Standard SNI 19-7119.1-2005. The equipment used in this study is shown in Figure 3.

Fig 3. Impinger

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

Point	Distance and Direction from Source	Titik Koordinat		Sampling Date (2025)
		x	y	
1	1000 m West	-5.1703023	119.4864544	7 February 2025
2	500 m West	-5.1733633	119.4861909	10 February 2025
3	Inside Landfill (Source	-5.1737923	119.4901854	12 February 2025
4	1000 m Southeast	-5.1810248	119.4928253	14 February 2025
5	500 m Southeast	-5.1854540	119.4929906	14 February 2025

"The NH_3 sampling was conducted on five separate days during the rainy season in February. At each sampling point, data were collected across four distinct intervals to capture diurnal variations: morning (06:00–10:00), afternoon (10:00–14:00), evening (14:00–18:00), and night (18:00–22:00). Within each interval, an active 1-hour sampling period was performed. This sampling design was established in accordance with the Regulation of the Indonesian Minister of Environment No. 12 of 2010, ensuring that the measurements represent various atmospheric conditions and landfill activity levels throughout the day. To ensure data reliability and capture diurnal variations, measurements at each point were replicated across four time intervals (morning, afternoon, evening, and night) as per the national monitoring standards

Table2. Meteorological Data Recapitulation

Location Point	Point	Meteorological Data	Interval			
			Morning	Midday	Afternoon	Night
1	Located 1000 meters west of the landfill site	Temperature	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	0.85	0.9	1.05
2	Located 500 meters west of the landfill site	Temperature	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)	2.05	1.45	1.33	1.35
3	Landfill site point	Temperature	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)	1.08	1.05	1.65	1.55
4	Located 500 meters southeast of the landfill site	Temperature	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)	2.55	3.25	2.75	2.35
5	Located 1000 meters southeast of the landfill site	Temperature	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)	1.05	2.4	1.15	1.55

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 those used in previous studies, including the research conducted by Latusanay and Suwendar (2021). 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 >500–1000 m). Each household was represented by one respondent of productive age (15–64 years) who resided in the vicinity of the landfill, thereby ensuring a 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, responses were grouped into two categories: "disturbed" (strongly agree and agree) and "not disturbed" (disagree and strongly disagree). A chi-square test was used to examine the association between respondent characteristics and odor disturbance perception.

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 administering the questionnaire. 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 consequence.

2.3 Data Analysis

The data analysis in this study involved data processing using Excel for concentration calculations, questionnaire data processing, and ArcGIS for visualization.

2.3.1 NH_3 Data Analysis

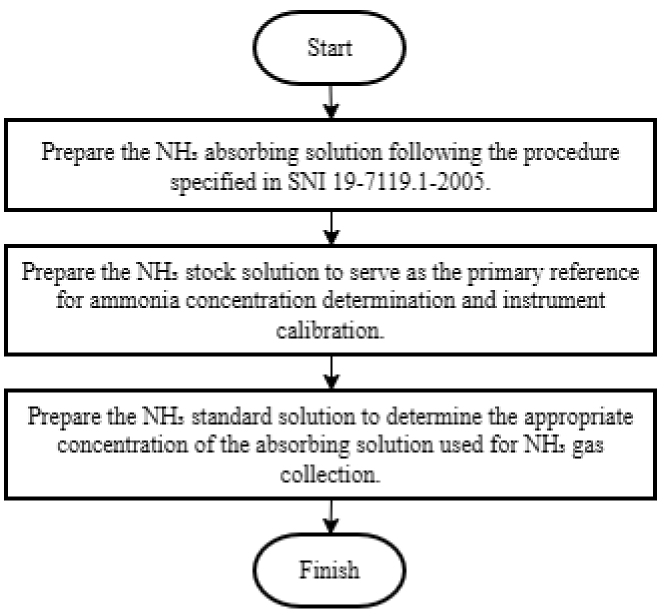
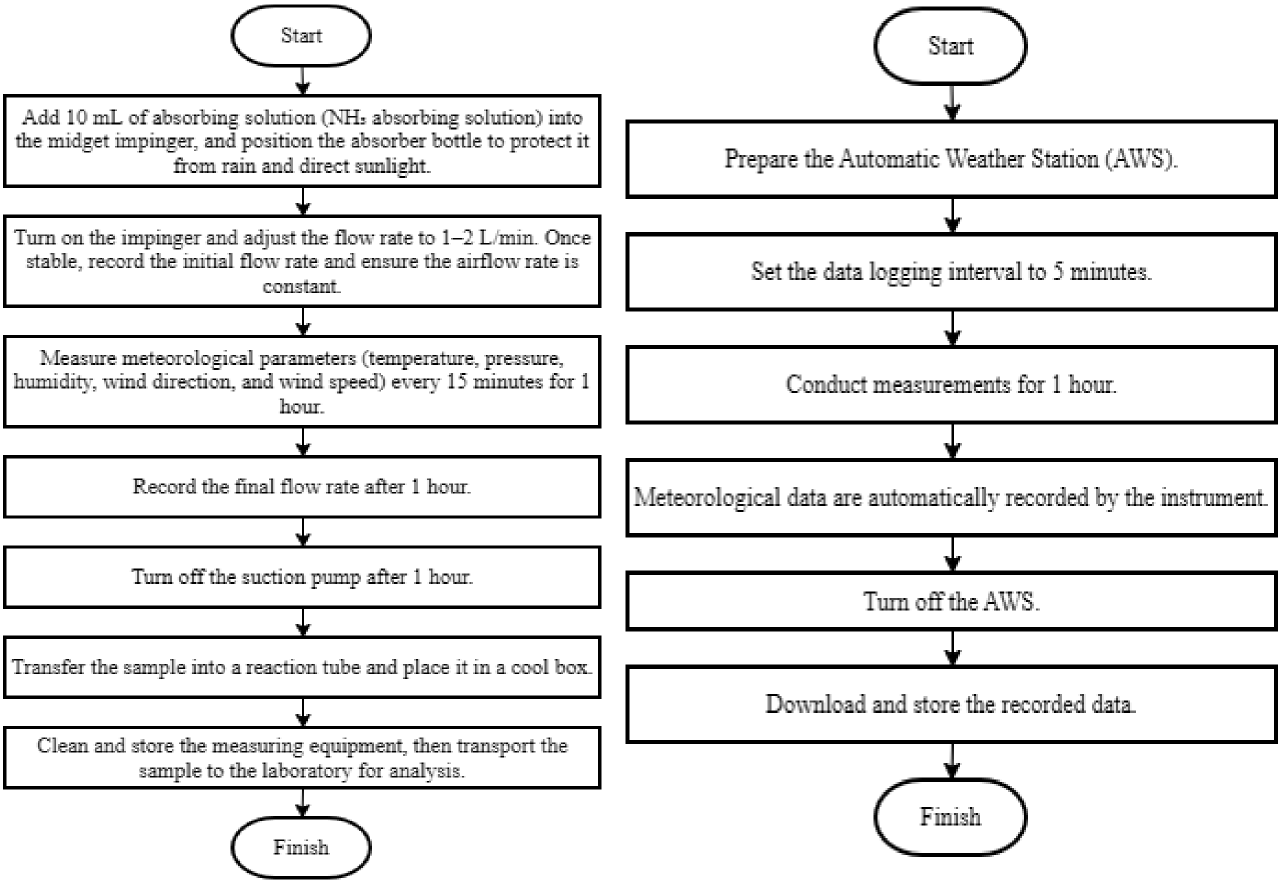


Fig 4. Ali Diagram of NH_3 Pollutant Data Processing

1.3.1.1. NH_3 Sampling and Meteorological Ammonia (NH_3) Sampling and Meteorological Data Collection



2.3.2 Visualization of NH_3 Gas Distribution

1. After determining the average concentration values obtained at each sampling point, a spatial visualization of NH_3 gas distribution was generated using the Inverse Distance Weighted (IDW) interpolation method in ArcGIS software. The resulting spatial distribution map is presented in Figure 6.

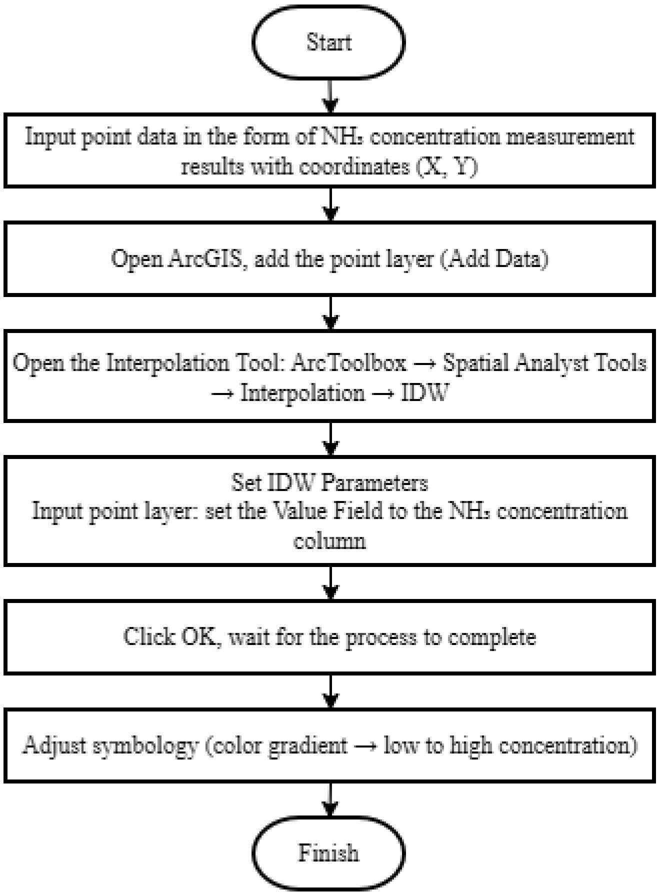


Fig 5. NH_3 distribution visualization flowchart

2. 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 can be determined using Sturges' formula (Rahman, 2019), as expressed in Equation (1):

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

where:

K = number of classes,

n = number of data sets.

2.3.3 Questionnaire Data Analysis

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

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

Note:

- P = Percentage Amount(%)
- F = Frequency of Responses
- *n* = Total number of Respondents

The percentage formula can be used to convert fractions into percentages. Percentages indicate how large a certain part is of the total amount. Source: Sugiyono (2017).

3. RESULTS AND DISCUSSION

3.1 Concentration of NH_3

The concentration of NH_3 was measured by taking samples every hour for four measurements based on the intervals of morning, afternoon, evening, and night. The results of ambient air sampling using an Impinger Air Sampler were then analyzed in the laboratory to obtain measurement results in ppm. The measurement results at point 1 can be seen in the figure. "To address the regulatory compliance of the measured ammonia (NH_3) concentrations, a comparison was made with the national odor standard. According to the Decree of the Minister of Environment No. 50 of 1996, the ambient limit for ammonia is set at 2 ppm. For clarity and as requested, these values have been converted to µg/Nm^3 (where 2 ppm is equivalent to approximately 1,393.05 µg/Nm^{3}at standard conditions of 25°C and 1 atm). Each data point represents a 1-hour averaging time, consistent with the required sampling protocol. The complete measurement results across all sampling points and time intervals are presented in

Table 3. Measured concentration of NH_3 at various sampling points and time intervals.

Sampling Point	Interval	Concentration (µg/Nm^3)	Concentration (PPM)	Status
Point 1	Morning	2.876	0.004	Within the regulatory limit
	Afternoon	90.710	0.130	Within the regulatory limit
	Evening	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
	Afternoon	130.632	0.188	Within the regulatory limit
	Evening	291.977	0.419	Within the regulatory limit
	Night	255.178	0.366	Within the regulatory limit
Point 3	Morning	2108.438	3.027	Exceeds the regulatory limit
	Afternoon	1663.853	2.389	Exceeds the regulatory limit
	Evening	1452.921	2.086	Exceeds the regulatory limit
	Night	4099.013	5.885	Exceeds the regulatory limit
Point 4	Morning	166.122	0.238	Within the regulatory limit

	Afternoon	79.099	0.114	Within the regulatory limit
	Evening	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
	Afternoon	19.629	0.028	Within the regulatory limit
	Evening	36.240	0.052	Within the regulatory limit
	Night	26.447	0.038	Within the regulatory limit

3.1.1 NH_3 Concentration Sampling Point 1

Based on the direct measurement results of ammonia (NH_3) concentration at Point 1, located 1,000 meters from the source (landfill site), sampling was conducted for 1 hour at each time interval (morning, afternoon, evening, and night). The measurement results indicate that all concentrations were still below the ammonia quality standard 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 unit was converted to 1393.04 µg/m³. The highest concentration was recorded in the afternoon at 90.71 µg/m³, while the lowest was observed in the morning at 2.88 µg/m³. The average concentrations obtained were 2.88 µg/m³ (morning), 90.71 µg/m³ (afternoon), 52.55 µg/m³ (evening), and 40.49 µg/m³ (night). The highest concentration was recorded in the afternoon at 90.71 µg/m³, while the lowest was observed in the morning at 2.88 µg/m³. The average concentrations obtained were 2.88 µg/m³ (morning), 90.71 µg/m³ (afternoon), 52.55 µg/m³ (evening), and 40.49 µg/m³ (night).

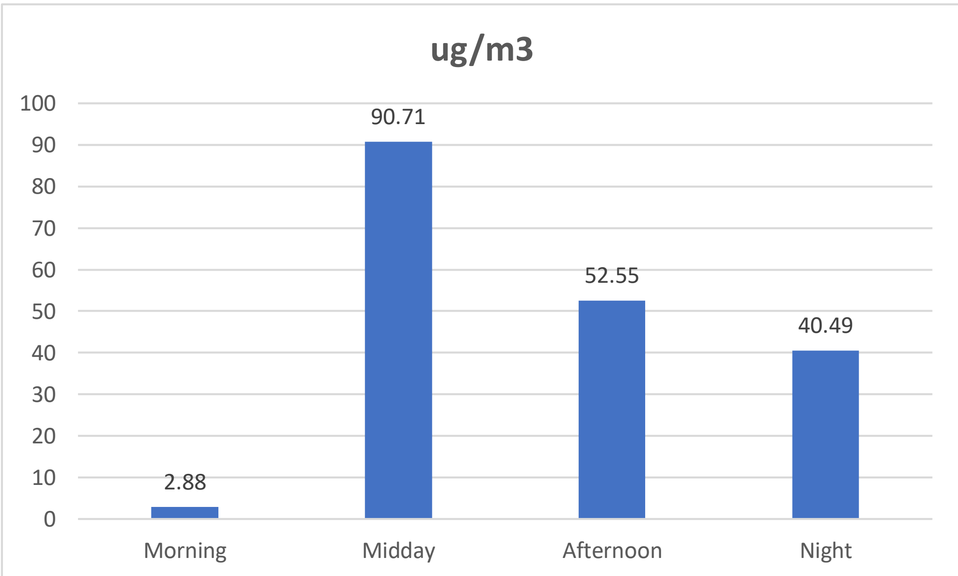


Fig 6. Ammonia concentration graph Sampling Point 1

3.1.2 NH_3 Concentration Sampling Point 2

Based on the direct measurement results of ammonia (NH_3) concentrations at Point 2, located within a 500-meter radius from the landfill site, sampling was conducted for 1 hour at each time interval. The results show fluctuating daily concentration variations. The lowest concentration was recorded at midday at 130.63 µg/m³, while the highest concentration occurred in the afternoon at 291.98 µg/m³. Meanwhile, the concentration in the morning was 156.14 µg/m³, and at night it reached 255.18 µg/m³, indicating a fairly significant increasing trend. 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 time intervals, all measured values remained well below the quality standard threshold of 2 ppm, equivalent to 1,393.04 µg/m³. Therefore, the ambient air quality at Point 2 is still considered safe, although the concentrations are higher compared to Point 1, which is located at a greater distance from the source.

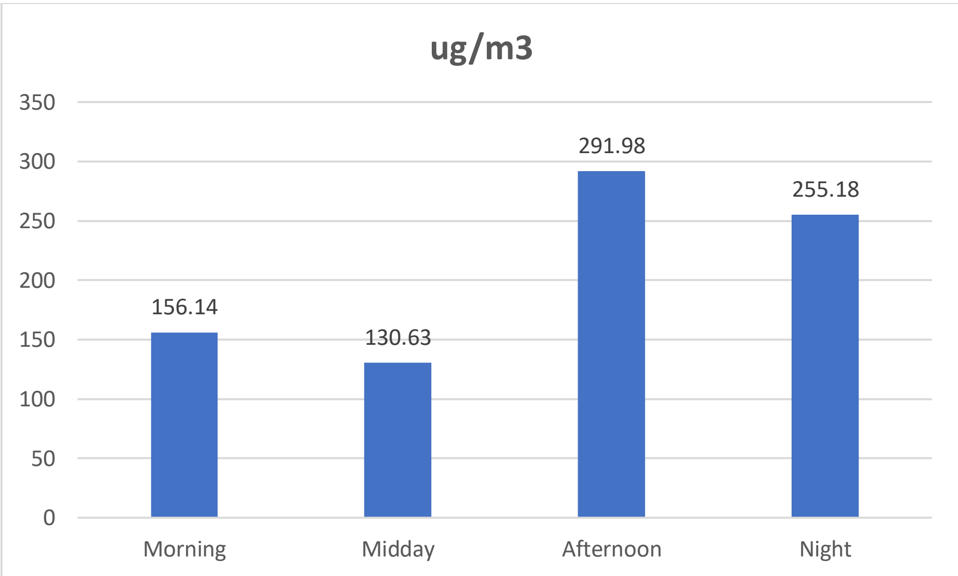


Fig 7. Ammonia concentration graph sampling Point 2

3.1.3 NH_3 Concentration Sampling Point 3

The results of ammonia (NH_3) concentration measurements at Point 3, which is located directly at the landfill emission source, showed higher concentrations compared with other monitoring points. Measurements were conducted for 1 hour during each observation interval, resulting in concentrations of 2,108.44 µg/m³ in the morning, 1,663.85 µg/m³ at midday, 1,452.92 µg/m³ in the afternoon, and 4,099.01 µg/m³ at night. All measured concentrations at Point 3 exceeded the odor threshold quality standard of 1,393.04 µg/m³ (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 µg/m³), which may be 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, 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 represents the location with the highest NH_3 concentration among all monitoring points, highlighting the landfill site as the primary emission source of ammonia in the study area.

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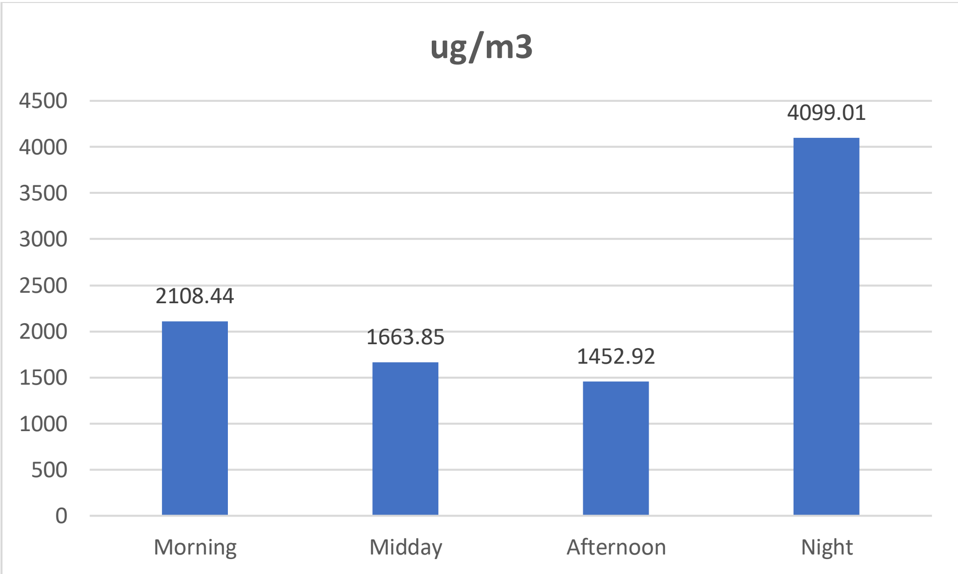

Fig 8. Ammonia concentration graph sampling Point 3

3.1.4 NH_3 Concentration Sampling Point 4

Based on the direct measurement results of ammonia (NH_3) concentrations at Point 4, located within a 500-meter radius from the landfill site toward the southeast, variations in concentration were observed at each time interval, indicating daily fluctuations. The highest concentration was recorded at night at 219.79 µg/m³, while the lowest concentration occurred at midday at 79.10 µg/m³. Meanwhile, the concentrations measured in the morning (166.12 µg/m³) and in the afternoon (170.90 µg/m³) were at moderate levels. This pattern shows an increase in concentration at night, which is likely influenced by more stable atmospheric conditions that promote gas accumulation near the ground surface. Nevertheless, all recorded concentrations remain well below the quality standard threshold of 2 ppm, equivalent to 1,393.04 µg/m³. Therefore, the air quality at Point 4 can be categorized as safe from ammonia pollution, despite the variations observed across measurement times.

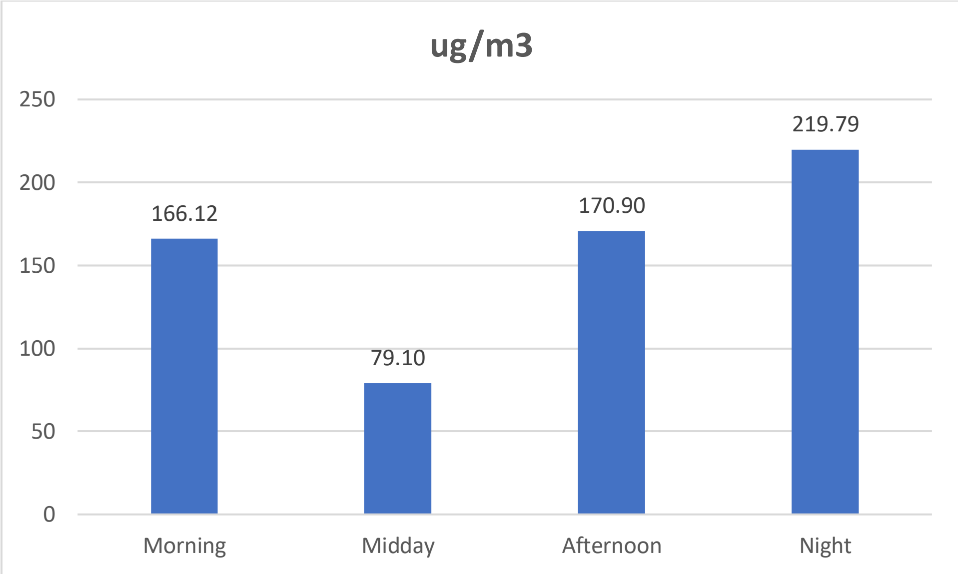

Fig 9. Ammonia concentration graph sampling point 4

3.1.5 NH_3 Concentration Sampling Point 5

Direct NH_3 measurements conducted over a 1-hour observation period at a distance of 500 m from the landfill (Point 5) demonstrated distinct temporal variation. The recorded concentrations were 2.87 µg/m³ in the morning, 19.63 µg/m³ at midday, 36.24 µg/m³ in the afternoon, and 26.45 µg/m³ 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 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.

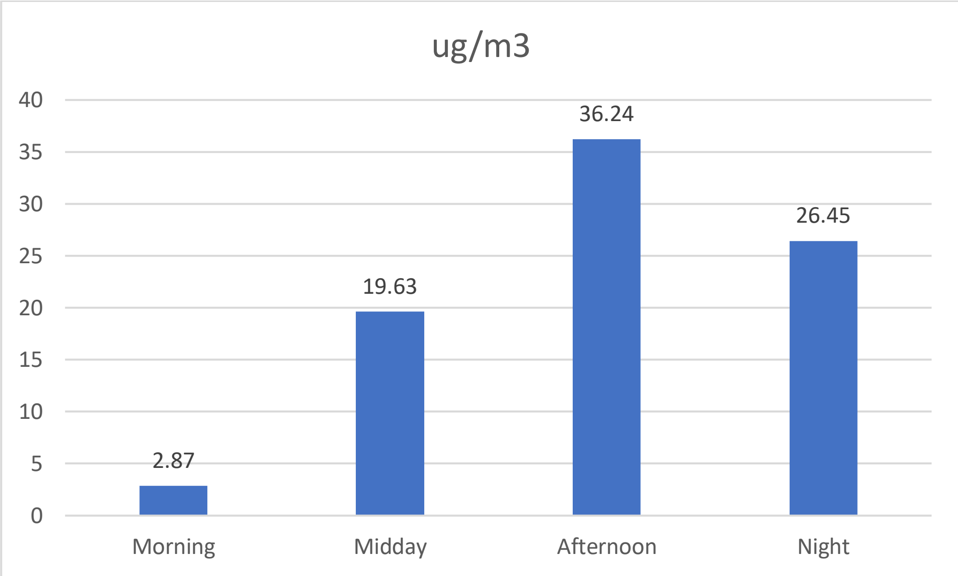

Fig 10. Ammonia concentration graph sampling point 5

Table 4. Correlation analysis between meteorological factors and NH3 concentrations at each sampling point.

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

Based on the normality test results presented in the table above, the Shapiro-Wilk test was selected for this study as it is specifically designed to assess the normality of small sample sizes ($N < 50$). All variables across each observation point yielded significance values (Sig.) greater than 0.05. This indicates that the data for all parameters including concentration, temperature, humidity, pressure, and wind speed are normally distributed at every observation point. Consequently, the data are deemed suitable for further analysis using parametric correlation tests, as they have fulfilled the fundamental assumption of normal distribution.

3.2. Visualization of NH_3 Concentration Distribution

he 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-hour 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 $\mu g/Nm^3$, which is higher than the equivalent regulatory threshold of 1,393 $\mu g/Nm^3$ (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. To visualize the spatial distribution pattern, Inverse Distance Weighting (IDW) interpolation was applied using the averaged 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.

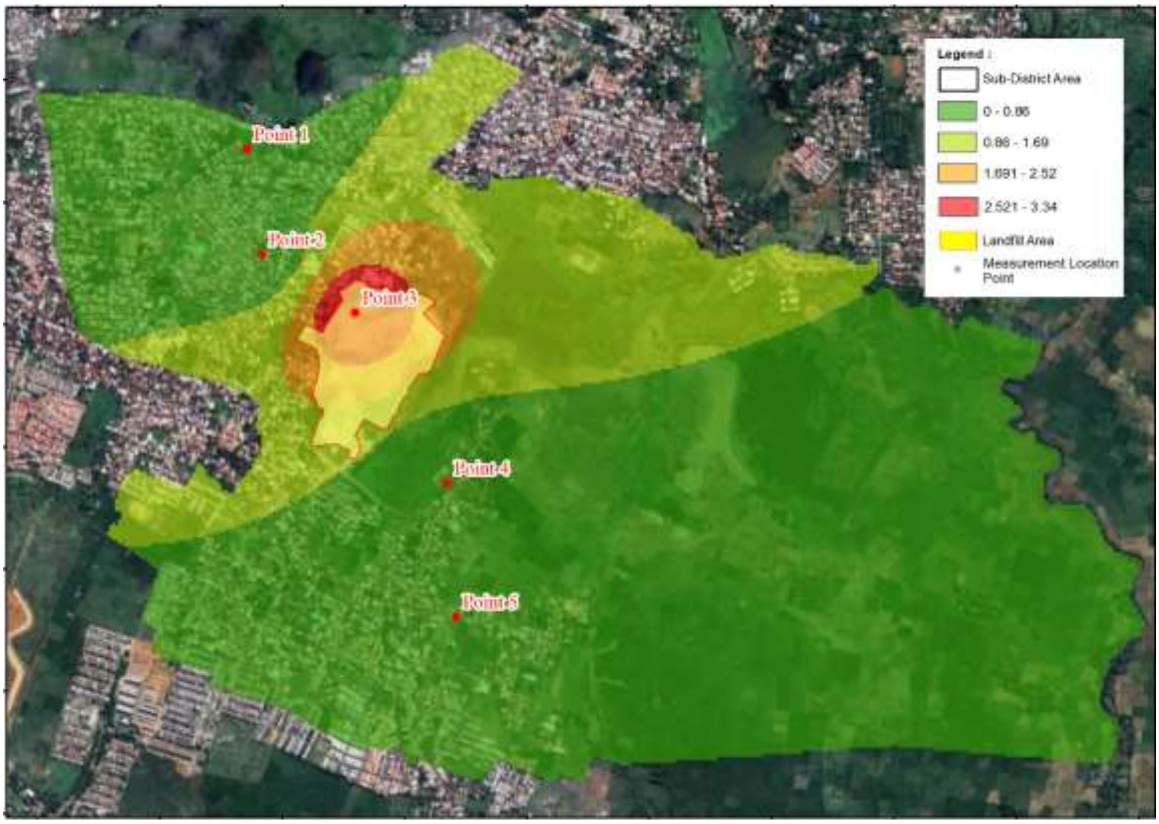

Fig 11. Visualization of NH_3 Distribution Patterns at the Antang Landfill

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

3.3.1 Disturbance Caused by Landfill Odor

Table 5. 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	

Based on the statistical analysis, Residential Distance and Orientation was identified as the only variable with a statistically significant relationship to the perceived level of odor disturbance ($p = 0.009 < 0.05$). Spatial patterns indicate that the Southeast sector bears the highest burden of disturbance, with 31% of respondents at distances between 500 m and 1 km consistently reporting subjective complaints. Conversely, in the West sector at a 500 m radius, the highest level of "Strongly Disagree" responses (11%) was recorded. This suggests that localized factors, such as prevailing wind patterns and topography, are more decisive 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/Bachelor's degree (30%) or Senior High School education (15%) reported disturbances, reflecting a higher environmental awareness among 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 respondents who felt undisturbed (15%) exceeded those who felt disturbed (10%). This indicates a state of sensory adaptation or habituation, where 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)

Table 6 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	**0.032**
	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 (0.0)	1 (100)	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	

Based on the statistical analysis, Residential Distance and Orientation is the only variable that shows 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 indicates that these perceived disturbances do not decrease linearly with distance. While respondents in immediate proximity (20 M) reported high concern (8% strongly agreeing), a notable peak of "Strongly Agree" responses (10%) was observed at 1 Km West. Conversely, respondents at 500 M West reported no significant disturbances (13 respondents in the "Disagree" category), suggesting 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 a statistically significant correlation with the reporting of health symptoms ($p > 0.05$). In terms of Gender, females reported a higher frequency of perceived disturbances (36% combined agreement) compared to 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 link environmental quality with physical well-being among the productive and educated population. The Occupation analysis reveals 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 perceives themselves as the most vulnerable to respiratory and olfactory discomfort. 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 symptoms and do not constitute a clinical medical diagnosis. They serve as subjective indicators of environmental nuisance and a perceived decline in the quality of life due to the landfill's operations.

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

Table 7. 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 (0.0)	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 (0.0)	3	
	Waste Picker	18 (58.1)	13 (41.9)	31	

The statistical analysis for Question 3 confirms that Residential Distance and Orientation is the only factor significantly associated with the community's perception of existing odor management measures ($p = 0.032 < 0.05$). The data reveals a predominantly critical perspective, particularly in the 1 km West and 20 m zones, where the majority of respondents expressed that current mitigation efforts by relevant authorities are inadequate. Interestingly, the 1 km Southeast sector showed a more polarized response (12 agree vs. 15 disagree), suggesting that the perceived effectiveness of management strategies is heavily influenced by localized exposure levels dictated by wind patterns and spatial positioning. While demographic variables such as Gender, Age, Education, and Occupation did not yield statistically significant correlations ($p > 0.05$), descriptive patterns highlight that respondents with Diploma/Bachelor's degrees (28 respondents) and those in the 31–40 age group (26 respondents) were the most critical of the current measures. Furthermore, Waste Pickers, who experience direct daily exposure, also showed a high level of agreement (18 respondents) regarding the insufficiency of odor control. In line with the reviewer's guidance, these findings should be interpreted as a perception-based assessment of environmental governance. They represent the community's level of dissatisfaction and the perceived gap between existing technical interventions and the actual reduction of environmental nuisance in their residential areas

3.3.4 Improvement of Waste Management at the Landfill is Needed

Table 8. 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	

The analysis of Question 4 reveals a unanimous social consensus across all respondent categories regarding the urgent need for improvements in waste management at the Antang Landfill. Unlike previous questions, statistical tests show no significant variation between groups ($p > 0.05$) because the agreement level reaches nearly 100% in every demographic and spatial category. This absolute consensus indicates that the demand for better management transcends geographic location, gender, age, education, and occupation. Spatially, even respondents in the West sector (who reported lower disturbance in earlier questions) joined those in the Southeast and immediate proximity (20 M) in demanding systematic reform. For example, in the 1 KM Southeast zone, 27 respondents (the largest group) recorded total agreement. This uniform response suggests that the communityregardless of their specific level of exposure collectively recognizes the current landfill operation as a critical environmental issue that requires immediate intervention. Demographically, the data shows that 98% of males and 99% of females support the need for improvement, with the "Strongly Agree" category dominating at 47% and 45% respectively. Furthermore, across all Educational Levels and Occupations, including Waste Pickers (24% strongly agree), there is a clear recognition that the current system is no longer adequate. In line with the reviewer's focus on perception-based assessments, this result underscores that the landfill's perceived impact has reached a threshold where the community across all social strata views environmental reform as a top priority for public health and local welfare. This collective demand provides a strong social mandate for authorities to upgrade waste management technologies and mitigate long-standing environmental nuisances.

4. CONCLUSION

Based on the converted odor threshold limit of 1394 µg/m³, exceedances were observed only at Sampling Point 3 (landfill source) across all time intervals, while concentrations at other locations remained below the regulatory threshold. The results of the study indicate that the highest ammonia (NH_3) concentration in the Antang landfill area occurred significantly at Sampling Point 3, which is located directly within the landfill site, reaching 5.885 ppm at night. This value exceeds the ambient NH_3 standard limit of 2 ppm. Meanwhile, Sampling Points 1 and 5, each located at a distance of 1,000 meters from the landfill, recorded the lowest ammonia concentrations of 0.004 ppm in the morning, remaining well below the permissible standard. The spatial distribution visualization shows that the highest concentrations, represented by red and orange colors, were concentrated around Point 3 and dispersed toward the northwest, covering Point 2 (500 m) and Point 1 (1,000 m). This pattern is strongly influenced by the dominant wind direction from southeast to northwest. In contrast, the lowest concentrations, indicated by dark green colors, were observed in areas located up to 1,000 m from the landfill, particularly toward the southeast at Points 4 and 5, demonstrating a gradual decrease in pollutant concentration with increasing distance from the emission source. Community perception analysis based on gender, age, education level, occupation, and residential distance revealed that 67% of respondents reported being disturbed by landfill odors. This disturbance was most pronounced among residents living within the closest radius and along the dominant wind dispersion pathway from southeast to northwest, particularly within 500 m of the landfill. In contrast, waste pickers tended to report less disturbance due to long-term habituation to the odor, despite continuous exposure. Furthermore, 63% of respondents reported experiencing health-related complaints such as dizziness, nausea, and shortness of breath. The majority of respondents also perceived that odor management efforts by relevant authorities were ineffective, and nearly 100% of respondents agreed that landfill management practices require significant improvement.

Policy Implications

The results of this study emphasize the need for stronger governmental responsibility in improving landfill management at the Antang landfill to reduce ammonia (NH_3) concentrations and minimize odor disturbances affecting nearby communities. Elevated NH_3 levels and widespread odor complaints indicate that existing waste management practices are inadequate to ensure environmental comfort and public well-being. Therefore, local authorities should prioritize more systematic landfill management and routine NH_3 monitoring, supported by spatial distribution mapping, to inform risk-based buffer zoning and urban planning. Integrating community perception data into policy evaluation is also essential to ensure that landfill management strategies effectively address both measured pollution levels and residents' lived experiences.

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Discussion

It should be noted that the spatial interpolation was based on five sampling points; therefore, the resulting distribution map provides a general representation of NH_3 concentration patterns rather than a high-resolution spatial model, It should be noted that the spatial interpolation was based on five sampling points; therefore, the resulting distribution map provides a general representation of NH_3 concentration patterns rather than a high-resolution spatial mode

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