JOURNAL OF
HYDRO-METEOROLOGY

Check for updates

Research Article

Application of TAPM-AERMOD model system to assess pollution spread and propose odor control solutions at Dap Da landfill, Dong Thap province

Ho Minh Dung[1]*, Nguyen Thi Thanh[1]

[1] Institute for Environment and Resources, VNU-HCMC; H_minhdung@yahoo.com; thanhier1011@gmail.com

*Corresponding author: H_minhdung@yahoo.com; Tel.: +84–903605245

Received: 25 December 2024; Accepted: 03 February 2025; Published: 25 March 2025

Abstract: Domestic solid waste landfills are sources of unpleasant odors that affect the lives of residents living nearby. It can be said that odor pollution is considered a pollution problem that has caused much concern for people living around landfills in recent times in Vietnam in general and also in Dong Thap province. This study was conducted to assess the status of odor pollution and apply the TAPM-AERMOD model system to simulate the spread of odor pollution at the Dap Da landfill, thereby proposed solutions to reduce odor pollution, contributed to protect the air environment around the landfill. The study calculated the emission load of NH_3, H_2S and CH_3SH from the Dap Da landfill based on the emission factors method. The results of the odor spread simulation showed that the highest average 1-hour concentration of NH_3 was 1000 µg/m^3, in range of 200-500 µg/m^3 with the farthest spread distance of 2 km and mainly in the Northwest direction; the highest average 1-hour concentration of H_2S was 165 µg/m^3, in range of 42-80 µg/m^3 with the longest spread distance of 2.1 km and mainly in the Northeast direction; the highest average 1-hour concentration of CH_3SH was 71.8 µg/m^3, in range of 50-70 µg/m^3 with the longest spread distance of 623 m and mainly in the Northeast direction. The study built 2 scenarios in the future when expand the landfill to 2050, showed that the pollutant concentration increased by 1.5-2.0 times, the spread distance increased by 1.3-1.5 times (in scenario 1) and 3.2-4.0 times (in scenario 2) to the current situation. In addition, the study proposed solutions to reduce odor pollution from the Dap Da landfill.

Keywords: Dap Da landfill; Odor pollution; TAPM-AERMOD; Pollution reduction.

---

1. Introduction

Odor pollution is one of the important environmental problems in domestic solid waste landfills (referred as landfills). Currently, air quality management in landfills is facing many difficulties, due to many reasons including waste classification and waste treatment techniques, etc. In recent times, there have been many concerns surrounding the odor pollution problem from the Dap Da landfill, Dong Thap province. If not thoroughly treated, the risks from odors will lead to air pollution, contribute to increase diseases and seriously affect people's health. Therefore, odor pollution control has become a key issue in the operation of current landfills. This study was conducted to assess the current status and level of odor pollution (through air pollutants NH_3, H_2S, and CH_3SH) from the Dap Da landfill by using the TAPM-AERMOD model system, thereby proposing effective odor control solutions. Studies on odor pollution in landfills mainly focus on the following main directions: concentration monitoring, emission factors estimate, calculation of pollutants emission load and simulation of pollutants concentration spread. In addition, there are other related studies such as assessing the impact of odor pollution from landfills on the health of surrounding residents, calculate greenhouse gas emissions, etc.

The study [1] developed an average odor emission factor based on the results of odor concentration measurements sampled at 7 different municipal solid waste landfills in Italy, to evaluate and predict landfill odor emissions. The study [2] conducted a study on odor pollution at the Tianziling landfill, Hangzhou, China. Up to 68 different volatile gases were identified, of which NH_3 and H_2S were the dominant gases and contributed to 83.91-93.94% and 4.47-10.92%, respectively. In addition, there are some of similar studies assessing odor pollution [3–6]. The study [7] compared methods for calculate odor emissions from landfills, including based on emission calculation models (LandGEM model), CH_4 concentration measurements, or direct odor concentration measurements. Several other studies have used models to calculate pollution emissions from landfills [8–11].

In Vietnam, research on odor pollution from landfills has not received much attention. Typically, in recent times, there have been the following studies: Research [12] has established emission factors for pollutants NH_3, H_2S, CH_4 and CH_3SH based on data of temperature, humidity, wind speed, atmospheric stability and concentrations at active and inactive landfills. Research [13] estimated the emission load of gases from the Nam Binh Duong solid waste landfill using the LandGEM model. Research [14] aimed to calculate the emission of major odorous gases from domestic waste landfills based on the IPCC CH_4 emission model. This study has determined the coefficients on the decomposition rate and the N, S fraction involved in the formation of NH_3, H_2S and CH_3SH. In addition, there are some other studies related to the calculation of greenhouse gas emissions (CH_4) in landfills [15–19].

Studies using models to assess the spread of odor pollution are quite diverse, but in general, some commonly used models are Gaussian models (ex. ISC3, AERMOD, ADMS), Lagrangian models (ex. CALPUFF, SCIPUFF), Euler models (ex. CMAQ, TAPOM, CALGRID). Research [20] evaluated the effectiveness of 2 models AERMOD and ISCST3 to simulate the spread of H_2S from Kahrizak landfill, Iran. The research results showed that the AERMOD model was more effective than the ISCST3 model. Research [21] applied the LandGEM model to calculate the emission load and the AERMOD model to simulate the pollutants CH_4, CO_2 and NMVOC from Shahrekord landfill, Iran. The study [22] simulated the diffusion of H_2S and 22 volatile organic compounds (VOCs) from a landfill site (in Istanbul, Turky) to the nearest surrounding residential area by using the ISCST3 model. The study [23] evaluated the H_2S emission from the Nakhon Si Thammarat landfill using the AERMOD model. The study [24] estimated the odor impact (of sulfur compounds) from the operation of a municipal solid waste landfill in Beijing, China, and used a Gausian dispersion model to simulate the spatial distribution of these concentrations. The study [25] calculated H_2S emissions based on monitoring results and used the CALPUFF model to simulate the diffusion of H_2S, evaluate the influence of wind direction, wind speed, area, and landfill height. Similarly, there is a study by [26] that used the CALPUFF model to assess the odor propagation to the vicinity of a landfill in the southwestern part of Poland. The study [27] performed CH_4 emission calculations using the traditional IPCC method and the LandGEM model for the Sarimukti landfill (Bandung city, Indonesia). Then, the AERMOD model was used to simulate the CH_4 spread assessment. In addition, there are some of studies based on the simulation results of odor pollution spread to assess health risks [28–30].

Studies simulating the odor spread of landfills in the country have not received much attention. Typically, research [14] conducted a study on odor spread from Da Phuoc landfill, simulating odor intensity based on simulating the concentration of odorants. Research [31] applied the ECOLAF-2014 model system to simulate NH_3, H_2S, CH_3SH, CH_4 for Da Phuoc landfill. In addition, research [32] calculated CH_4 emissions (using the LandGEM model) and used the EnLandFill model to simulate CH_4 spread at Phuoc Hiep landfill.

The above overview shows that there have been many studies using the AERMOD model for air quality simulation studies in general and for odor pollution spread simulation at landfills in particular. The above studies show that the AERMOD model has been applied to simulate odroants effectively, with high correlation values between simulation results and obserbed data. In addition, the combination of the TAPM-AERMOD model system to simulate odor pollution spread from landfills is still limited. However, this model system has been applied quite well in other fields, especially in typical industrial activities, some of the following studies: Simulation study of the spread of air pollutants from Giao Long Industrial Park, Ben Tre [33]; Simulation study of air pollution spread at Phu My 2 Industrial Park and Phu My 2 expansion, Ba Ria - Vung Tau province [34]; Research on simulate the spread of air pollution from steel factories in Phu My town area [35]; Application of TAPM-AERMOD model to simulate air pollutants from ports [36]; Assessment of the spread of air pollution from livestock activities [37], and some other studies. Therefore, in this study, the authors will choose the TAPM-AERMOD model system to carry out the study.

2. Materials and Methods

2.1. Study area

The Dap Da landfill is built on a geological foundation of agricultural land with an area of 25.04 hectares in My Tho commune, Cao Lanh district, Dong Thap province [5]. The construction site is located about 9 km southwest of the center of Cao Lanh district (Figure 1). The landfill is built with the following items: Waste treatment area (including 02 cells: The first cell 72,000 m^3 (stopped operating in mid-May 2013); The second cell 70,000 m^3 (operated in May 2013); The preliminary leachate treatment area includes 02 leachate pumping stations from the garbage cell to the wastewater reservoir with a flow rate of 20 m^3/h; 03 leachate reservoirs; Equalization pond (receiving leachate then treating it with biological products and settling sediment); Stabilization pond (receiving leachate from the equalization pond, where the settling process takes place and continues to treat odors, disinfect wastewater before going to the biological pond); Biological pond (planting aquatic plants to receive and treat leachate from the stabilization pond); Septic sludge treatment and stabilization tank mainly treats septic tank feces. In addition, there is a green embankment surrounding the landfill with a length of about 2,500 m. After being collected, household waste will be re-sorted into recyclable products sold to scrap collection facilities, the remaining waste will be treated for odors and insects, then leveled and compacted. When the cell is full according to the plan, the garbage will stop being dumped to treat chemicals, lime will be spread to stabilize the waste, and then soil will be covered on the surface of the cell.

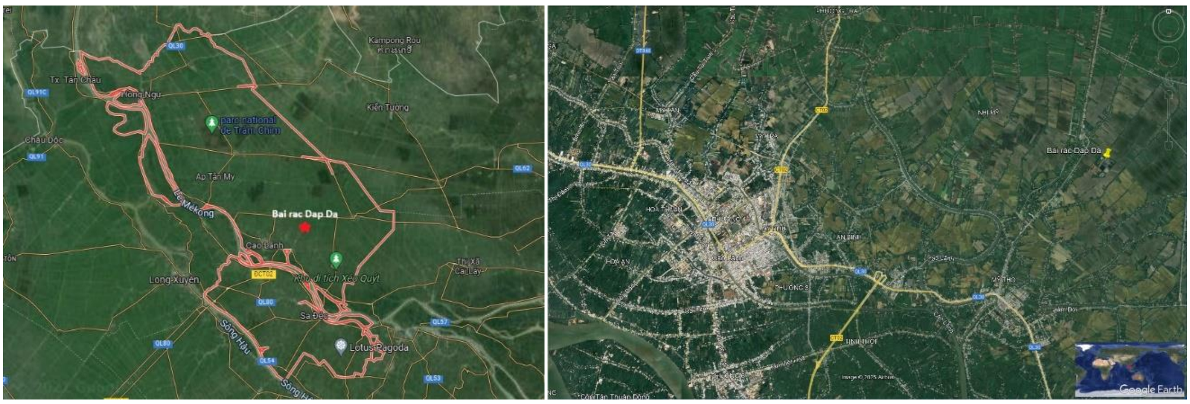


Figure 1. Location of Dap Da landfill.

2.2. Research content

- Overview of research related to the topic to argue the necessity of implementing the topic, at the same time providing evidence as a scientific basis for selecting an effective odor spread simulation model from the landfill; Collecting data from the Dap Da landfill from the landfill management board, the Department of Natural Resources and Environment of Dong Thap province on meteorological characteristics, landfill characteristics of the Dap Da landfill; landfill technology diagram, design capacity, operating form and operating time; the volume of solid waste buried at the landfill from the time of operation to the time of the study.
- Assessing the current status and calculating the amount of odor emissions from the Dap Da landfill: Using field survey methods for investigating, surveying the site, observing and saving images to collect general information, the actual situation to know the existing status, thereby assessing the current status of odor pollution of the Dap Da landfill; Inheriting the results of monitoring the concentration of some odorous substances (NH_3, CH_4, CH_3SH) at the Dap Da landfill to assess the current status of odor pollution and simulate the odor spread of the Dap Da landfill; Collecting, processing data and selecting emission coefficients, calculating the emission of some odorous substances from the Dap Da landfill area as input data for the model.
- Building a map of the concentration spread of some odorous substances from the Dap Da landfill. Meteorological simulation using the TAPM model: Collected global meteorological data; Established the TAPM meteorological model for the Dap Da landfill; Modeled the TAPM model for the study area; Calibrated and validated the TAPM meteorological model: Collecting local meteorological monitoring data to serve the calibration and verification of the meteorological model. Simulated the spread of odorants by using the AERMOD model: Establishing the AERMOD model for the Dap Da landfill; Calibrate and verify the results of simulation of the spread of some odorants in the study area; Simulate the spread of some odorants in the Dap Da landfill; Comment and evaluate the results of simulation of the spread of some odorants at the Dap Da landfill.
- Propose solutions to reduce and control some odorants from the Dap Da landfill: Based on the simulation results, propose solutions to control some odorants from the Dap Da landfill.

2.3. Methodology

2.3.1. Methods of data and information collection

This method collects, analyzes and synthesizes sources of documents, materials, data, and available documents from documents, reports from Departments, Boards, Sectors and landfill management boards and inherits research results from previous studies as input data sources for the topic. The collected data are as follows: Documents related to the topic; Emission status data in the research area from the Department of Natural Resources and Environment of Dong Thap province, Department of Natural Resources and Environment Cao Lanh district,; Types of maps and images related to the topic; Meteorological data in the research area; Selecting emission coefficients to calculate odor emissions from the Dap Da landfill; Collecting studies related to the topic from within and outside the country. The data collection method is used to synthesize all secondary data to serve the processes of analyzing the current situation and simulating odor spread of the landfill.

2.3.2. Field investigation and survey methods

The method of investigation and field survey aims to help understand the actual situation, to know the existing shortcomings and difficulties in the management of odor pollution at the Dap Da landfill. Field survey of the actual status of odor sources, actual operating capacity, total amount of buried waste, landfill area, information on the technological chain and landfill operation efficiency. The information to be investigated includes: total area, buried area, open area when buried, remaining area (not used), leachate reservoir area, biological pond area, average amount of buried waste, amount of generated leachate, treatment measures, etc. At the same time, through the actual survey, representative monitoring locations are selected to serve the assessment of the current status of odor pollution in the landfill area and to serve the verification of simulation results of the spread of odor-causing substances. The monitoring locations and coordinates of the monitoring points are as shown in Figure 2 and Table 1. Monitoring parameters are NH_3, H_2S, CH_3SH; Sampling phase 1 (in dry season) on April 22-23, 2022 and phase 2 (in rainy season) on September 16-17, 2022.

Figure 2. Sampling location diagram.

Table 1. Coordinates of monitoring location.

VT1	VT2
10°28’31.72”N 105°43’15.38”E	10°28’41.95”N 105°43’10.67”E
VT3	**VT4**
10°28’29.70”N 105°43’0.60”E	10°28’23.53”N 105°43’8.55”E

Table 2. Allowable limits and odor thresholds of air pollutants.

No.	Parameter	Unit	QCVN 05:2023/BTNMT	Odor threshold [38]
1	H_2S	μg/m^3	42	0.7
2	NH_3	μg/m^3	200	26.6
3	CH_3SH	μg/m^3	50	0.04

2.3.3. Method of calculating odor emission

From the emission coefficient per unit surface area of the surface source, the emission load of surface source pollutants can be calculated to assess the impact of ambient air pollution from surface sources according to the formula:

$$M = \frac{Q \times S \times 1000}{3600} \quad (1)$$

where M is the emission load (g/s); Q is the pollution emission coefficient (mg/m^2.h); S is the surface source area (m^2). Odor emission coefficient applied for the study is in Table 3.

Table 3. The odor emission factor from landfill (g/m^2.s).

Type of landfill	H_2S	NH_3	CH_3SH	Source
Active	16,08 × 10^{-6}	14,93 × 10^{-6}	2,43 × 10^{-6}	[31]
Inactive	1,68 × 10^{-6}	6,70 × 10^{-6}	0,73 × 10^{-6}	

2.3.4. Modeling method

- The TAPM (The Air Pollution Model) is a model of the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO), used to simulate meteorological conditions and air pollution concentrations in 3D. Therefore, the model can be used as a meteorological support tool for air pollutant dispersion models, especially the input meteorological file for the AERMOD model. This function has also been improved for the TAPM V4 version when integrating the surface meteorological file format and altitude meteorological file for AERMOD. Meteorological conditions are used in the form of an

Eulerian model with functions for calculating wind, temperature, pressure, etc. and calculating atmospheric stability. With the second function, air pollution simulation is modeled according to the Lagrangian granular model, which can be applied to many types of sources, etc. taking into account the conditions of photochemical reactions, dry and wet sedimentation, gravitational sedimentation, etc. The model proves its advantage over Gaussian models and the function of calculating air pollution simulation when chemical reactions occur, giving more accurate results. The TAPM model simulates detailed meteorology using nested grids. In this study, the number of simulation domains is chosen to be 5 in order from large to small and this number of domains ensures detailed simulation size for the study area (Figure 3): The size of domain 1 is shown in the main interface with 25×25 grid cells (grid size is 30 km × 30 km); Domain 2 is shown in the interface with 25×25 grid cells with grid size is 10 km × 10 km; Domain 3 is shown in the interface with 25×25 grid cells with a grid size of 3 km × 3 km; Domain 4 is shown in the interface with 25×25 grid cells with a grid size of 1 km × 1 km; Domain 5 is shown in the interface with 25×25 grid cells with a grid size of 0.3 km × 0.3 km. The number of grid cells according to the elevation is nz = 25 selected, meaning that there will be 25 vertical grid cells in the elevation range from 10 m to 8 km.

Input of TAPM meteorological model: Global meteorological observation data, information about the simulation area (such as coordinates, location, terrain). TAPM model outputs meteorological data files as input data for AERMOD model. To simulate the meteorology for the study area, it is necessary to select appropriate boundary conditions for the study area such as: The selected central coordinates UTM are 48P 579784.00 and 1158153.00; Simulation period for the whole year 2022.

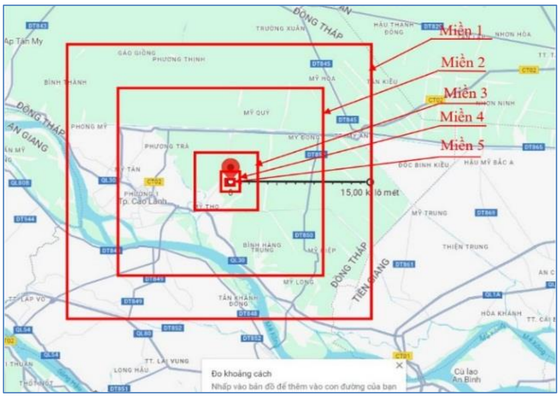


Figure 3. Meteorological simulation domains.

- AERMOD model (Figure 4): The AMS/EPA Regulatory Model (AERMOD), consists of three components: AERMOD (AERMIC Dispersion Model); AERMAP (AERMOD Topographic Tool) and AERMET (AERMOD Meteorological Tool). The AERMOD model was developed by the US National Weather Service and the Environmental Protection Agency. The AERMOD model includes a range of options for simulating air quality impacts from emission sources, building popular options for many applications. AERMET processes surface and inter-layer meteorological data, allowing the calculation of atmospheric parameters according to the Monin-Obukhov model. AERMAP integrates models that take into account topography. AERMET incorporates data from WebGIS to generate topographic files for the model. From the above data, AERMOD will produce simulation results in the form of 2D and 3D spatial images and export them via Google Earth to help users easily see the impacts of emissions on the study area. The grid resolution and study area are 50 km × 50 km. With the number of grid cells being 100 grid cells x 100 grid cells, the size of a grid cell is 0.5 km × 0.5 km. To implement the AERMOD model, we need to prepare input data for the model.

Meteorological data: To obtain the default meteorological files to run the AERMOD software, two types of data need to be collected, "Surface data" and "Upper air data". In this study, the TAPM model is used to extract "Surface data" and "Upper air data" as input data for AERMOD.

Emission source data: Emission source data for AERMOD includes the following data: Area coordinates; Elevation of the study area above sea level; Source height; Emission load; Width and length of the area. The area source is the main source mentioned in calculating the emission of some odorants from the landfill.

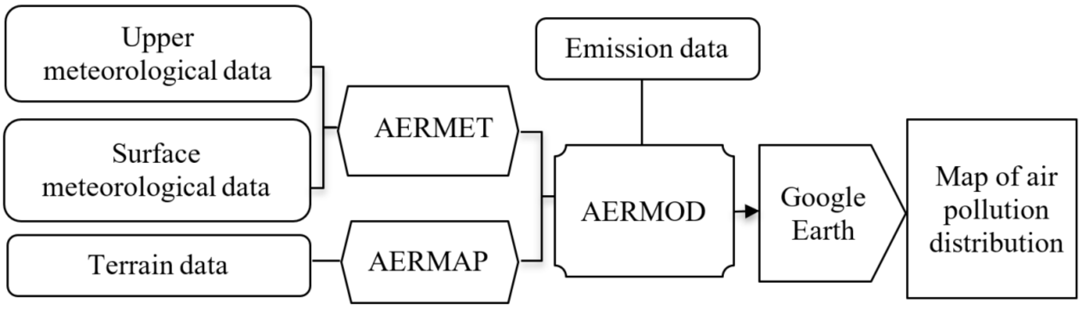


Figure 4. Simulation steps according to the AERMOD model.

Terrain data: AERMOD terrain data is processed using the AERMAP module.

- Calibration and verification: Statistical indicators used to evaluate the accuracy of the model include: Simulation error S (%); R coefficient to evaluate the correlation between simulated and observed values; root mean square error (RMSE), mean absolute percentage error (MAPE), etc. If the S value $\leq$ 15% and the R value $\geq$ 0.6, the simulation results are close to actual conditions. Using meteorological monitoring data from the Cao Lanh automatic air monitoring station (at 262 Ton Duc Thang, My Phu Ward, Cao Lanh City, Dong Thap Province; Coordinates: 10°28’16.91”; 105°38’41.99”) to validate the TAPM model; And using monitoring data at the landfill on April 22 & 23, 2022 (in dry season); September 16-17, 2022 (in rainy season) to validate the AERMOD model.

3. Results and discussion

3.1. Current status of odor pollution at Dap Da landfill

In the dry season (Figure 5), the highest average 1-hour concentration of NH_3 at VT1 exceeded the threshold by 1.3 times; the highest average 1-hour concentration of H_2S exceeded the threshold by 1.9 times compared to QCVN 05:2023/BTNMT; The average 1-hour concentration of CH_3SH at locations VT1, VT2, VT3, VT4 all met QCVN 05:2023/BTNMT. In addition, the average 1-hour concentration of some odorants at VT1 was the location causing the greatest odor pollution, while all survey parameters at VT2, VT3, VT4 met QCVN 05:2023/ BTNMT; In the rainy season (Figure 6), the highest average 1-hour concentration of NH_3 at VT1 exceeded the threshold by 1.2 times; the highest average 1-hour concentration of H_2S exceeded the threshold by 1.9 times compared to QCVN 05:2023/BTNMT; The average 1-hour concentration of CH_3SH at all locations meets QCVN 05:2023/BTNMT. The average 1-hour concentrations of NH_3, H_2S, CH_3SH at VT2, VT3, VT4 all meet QCVN 05:2023/BTNMT. Although there are still some times at the monitoring locations, the average 1-hour concentrations of NH_3, H_2S, CH_3SH do not exceed the standard, but exceed the odor recognition threshold. This is the reason why when monitoring, although the average 1-hour concentration of some odorants does not exceed the QCVN 05:2023/BTNMT, people around the landfill area feel an unpleasant stench.

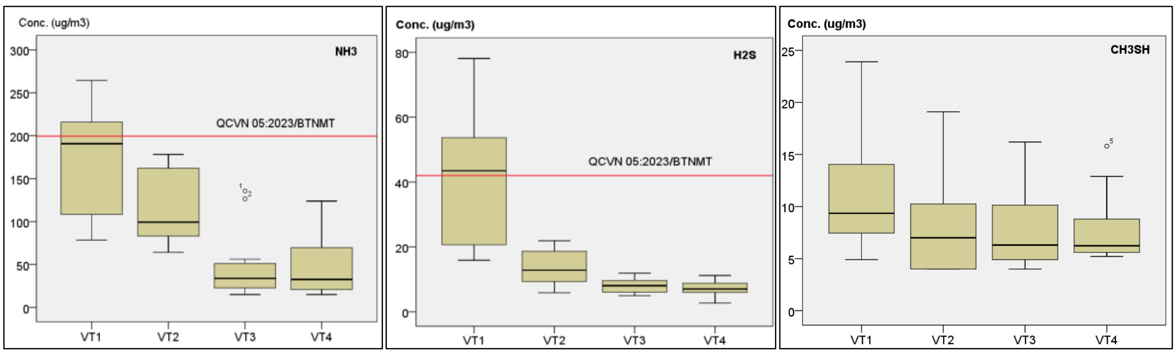


Figure 5. Concentration of NH_3, H_2S, and CH_3SH at VT1, VT2, VT3 & VT4 in dry season.

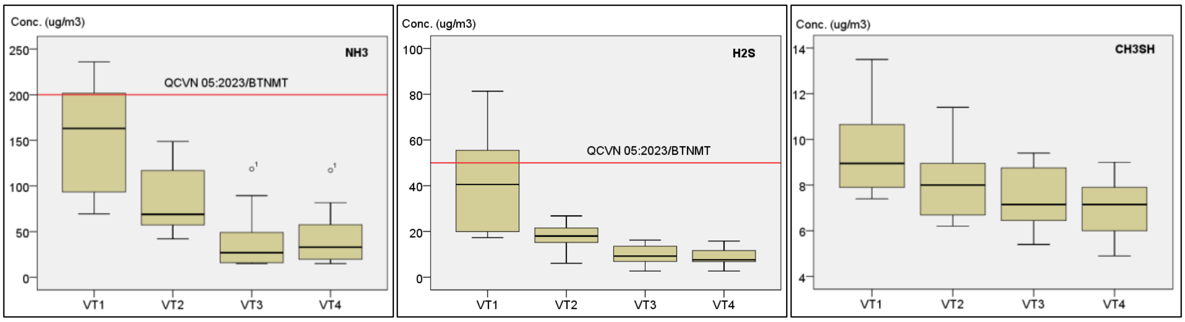


Figure 6. Concentration of NH_3, H_2S and CH_3SH at VT1, VT2, VT3 & VT4 in rainy season.

3.2. Assessment of odor spread from landfill area to surrounding area

3.2.1. Calculation of odor emission load

The controlled landfill area (covered with tarpaulin) has emissions equal to 10% of the uncontrolled area (open to receive waste) [12]. Therefore, the emission factor will be equal to 10% of the uncontrolled area. Calculation results of the emission load from the landfill Table 4.

Table 4. Emission load results (kg/year).

H_2S	NH_3	CH_3SH
1.730	2.233	158

3.2.2. Building scenarios to simulate the spread of odor pollution

Building scenarios to simulate the spread of odor pollution according to Decision No. 26/QD-UBND dated February 2, 2021 approving the expansion project of Dap Da landfill into My Tho Environmental Treatment Technology Center by 2050, the landfill will be expanded with a land use scale of 77.4 hectares, expanding 4 more landfill cells with an area of 14,427 hectares [22]. In addition, along with the future population and socio-economic development planning of the province, the selection of the following 2 emission scenarios is to assess the level of spread as well as the concentration of odorous substances in the study area: Scenario 1 (KB1): Forecast the level of pollution spread when increasing the emission value of odorous substances by 1.5 times compared to the current status (assuming when 2 landfill cells of the landfill expansion project come into operation); Scenario 2 (KB2): Forecasting the level of pollution spread when increasing the emission value of odorous substances by 2 times compared to the current situation (assuming when 4 landfill cells of the landfill expansion project come into operation).

3.2.3. Model calibration and validation

- TAPM model verification: The results of the simulated temperature verification from March 18-24, 2022 (in dry season) showed that the simulated temperature was relatively accurate with the temperature of Cao Lanh monitoring station, the correlation coefficient R reached a high value of 0.76-0.92 (Figure 7a); MAPE ranged from 3-7%; RMSE ranged from 2.67-3.50^oC. The verification of wind speed and wind direction showed that the simulated wind direction was relatively consistent with the wind direction of Cao Lanh monitoring station, reaching 90%. The results of the simulated temperature verification from August 12-18, 2022 (in rainy season) showed that the simulated temperature was relatively close to the temperature of Cao Lanh monitoring station, the correlation coefficient R between the simulated value and hourly monitoring reached a high value of 0.78-0.91 (Figure 7b); MAPE ranged from 3-7%; RMSE ranges from 1.87-3.54^oC. Wind speed and wind direction testing shows that the simulated wind direction is relatively consistent with the wind direction of Cao Lanh monitoring station, reaching 90%. Meteorological simulation results in 2022 show that in the dry season, the dominant wind direction is Northeast wind; in the rainy season, the dominant wind direction is Southwest monsoon.

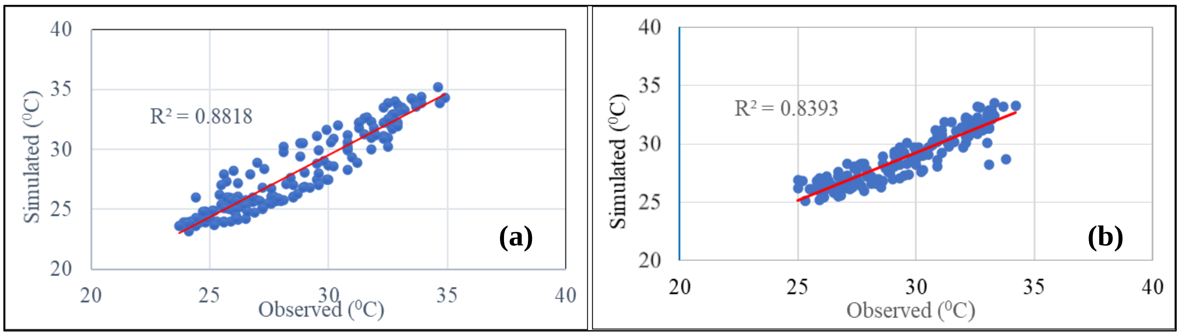


Figure 7. (a) Correlation temperature between simulated and observed values in dry season; (b) Correlation temperature between simulated and observed values in rainy season.

- AERMOD model verification: The data used to verify the odor pollution spread model is inherited from the monitoring data at the Dap Da landfill (using monitoring data on April 23-24, 2022 and September 16-17, 2022). The result of calculating the average standardized error MNBE between the simulated and observed values is 10.3% (ranging from -9.9% to 13.5%). This error result is within ± 15%. Therefore, the AERMOD model is capable of simulating odor pollution spread for the study area.

3.2.4. Evaluation of simulation results of odor spread from Dap Da landfill

a) Evaluation of simulation results of odor spread at Dap Da landfill (current status)

The simulation results of NH_3 concentration spread show that 10/12 months in 2022 have the highest average 1-hour concentration of NH_3 exceeding the QCVN 05:2023/BTNMT (Figure 8a) from 1.4-5.0 times and many times higher than the odor threshold. The area with the highest average 1-hour concentration of NH_3 is mainly concentrated in the area inside the landfill (in Mar., Apr., and Oct.). The area with concentration values from 200-500 µg/m^3 has the farthest spread distance of 2 km. The main spread direction for odorants is the West and Northwest (Figure 8b).

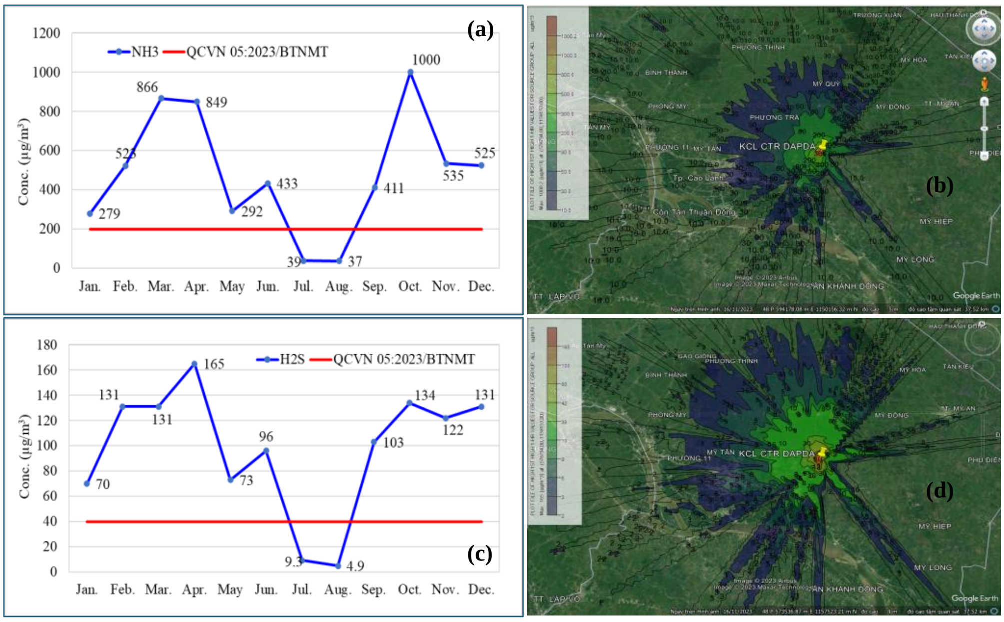


Figure 8. (a) Simulation results of the highest average 1-hour concentration of NH_3 (in current status); (b) Simulation map spread of average 1-hour concentration of NH_3 (in current status); (c) Simulation results of the highest average 1-hour concentration of H_2S (in current status); (d) Simulation map spread of average 1-hour concentration of H_2S (in current status).

The simulation results of H_2S concentration spread show that 10/12 months in 2022 have the highest simulated average 1-hour concentration exceeding the QCVN 05:2023/BTNMT threshold (Figure 8c) from 1.8-4.1 times and many times higher than the odor threshold. The area with the highest average 1-hour concentration of H_2S is mainly concentrated at the landfill where the two burial cells are adjacent, especially in Feb., Mar, Apr., Oct., Nov. and Dec.. The area with concentration values ranging from 42-80 µg/m^3 has the farthest spread distance of 2.1 km. The main spread direction for odorants is the West and Northwest (Figure 8d).

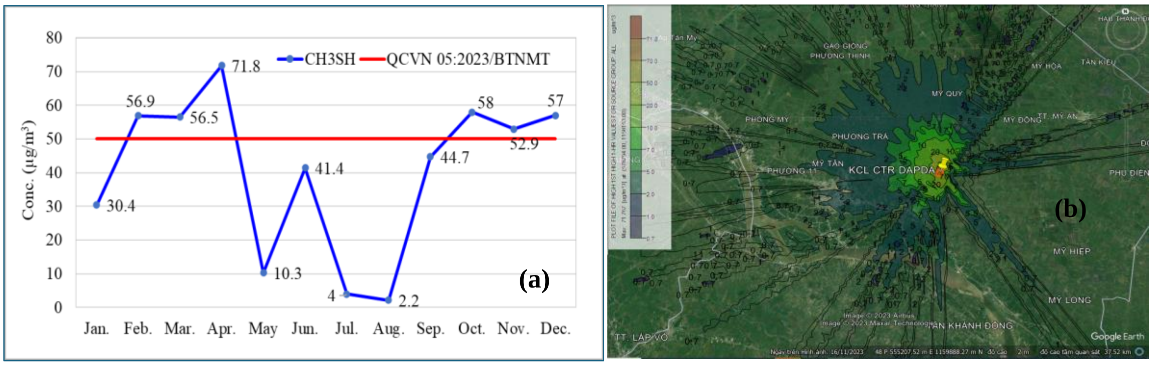


Figure 9. (a) Simulation results of the highest average 1-hour concentration of CH_3SH (in current status); (b) Simulation map spread of average 1-hour CH_3SH concentration (in current status).

The simulation results of CH_3SH spread show that 6/12 months in 2022 have the highest simulated average 1-hour concentration exceeding the QCVN 05:2023/BTNMT threshold (Figure 9a) by 1.1-1.4 times and many times higher than the odor threshold. The area with the highest average 1-hour concentration of CH_3SH is mainly concentrated at the landfill, especially in April. The area with concentration values ranging from 50-70 µg/m^3 has the farthest spread distance of 623 m and mainly spread in the Northeast direction. The main spread direction for odorants is the West and Northwest (Figure 9b).

b) Evaluation of odor spread simulation results for landfill area according to KB1

The simulation results of NH_3 spread according to KB1 show that 10/12 months have average 1-hour concentrations exceeding the threshold by 2.8-10 times (Figure 10a). The simulated values of average 1-hour NH_3 concentration ranging from 200-900 µg/m^3, spread distance of 3.6 km and in the Northwest direction. Compared to the current situation, the spread distance is 1.8 times farther.

The simulation results of H_2S spread according to KB1 show that the average 1-hour concentration in 10/12 months exceeded the threshold by 3.5-8.3 times (Figure 10b). At the time with the highest average 1-hour H_2S concentration value is in range 42-100 µg/m^3 with the farthest spread distance of 3.2 km. Compared to the current results, the H_2S spread distance increased by about 1.6 times.

The simulation results of CH_3SH spread according to KB1 show that the average 1-hour concentration in 10/12 months exceeded the threshold by 1.2-2.9 times (Figure 10c). The highest average 1-hour CH_3SH concentration in range 50-100 µg/m^3 with the farthest spread distance of 1.4 km and the main spread direction is Northwest. Compared to the current situation, the spread distance increased by 2.1 times.

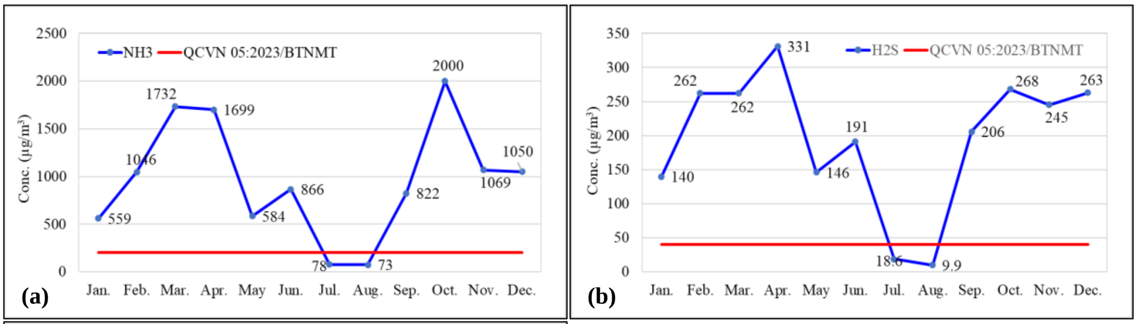
c) Evaluation of odor spread simulation results for Dap Da landfill according to KB2

The simulation results of NH_3 spread according to KB2 show that 10/12 months have the highest average 1-hour concentration exceeding the threshold by 4.2-15 times (Figure 11a). The area with concentrations in range 200-1,000 µg/m^3 has a spread distance of 4.8 km from the center of the landfill and spread in the Northwest direction. Compared to the current situation, the spread distance is 2.4 times farther.

The simulation results of H_2S spread according to KB2 show that 10/12 months have the highest average 1-hour concentration exceeding the threshold by 5.2-12.4 times (Figure 11b). The area with concentrations in range of 42-200 µg/m^3 has a spread distance of 4.8 km and is mainly spread in the Northwest direction. Compared to the current situation, the spread distance increased by 2.5 times.

The simulation results of CH_3SH spread according to KB2 show that 10/12 months have the highest hourly average concentration exceeding the threshold by 1.8-4.3 times (Figure 11c). The area with concentrations ranging from 50-100 µg/m^3 has a spread distance of 2.1 km and the main spread direction is Northwest. Compared to the current situation, the spread distance increased by 3.8 times.

In general, the highest average 1-hour concentrations of NH_3, CH_3SH, and H_2S in the months in the area inside the landfill exceeded the QCVN 05:2023/BTNMT threshold in both KB1 and KB2. When the odor emission increases by 1.5 times, the spread distance will increase by about 1.3-1.5 times, when the emission increases by 2 times, the spread distance increases by about 3.2-4 times.



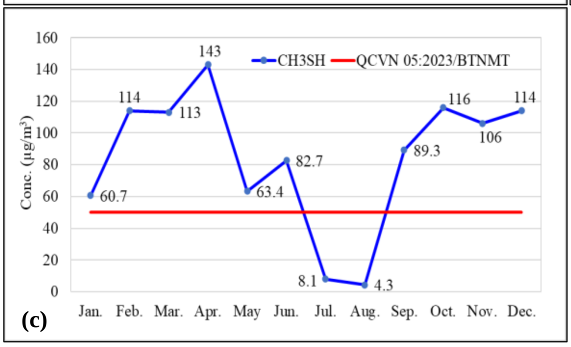
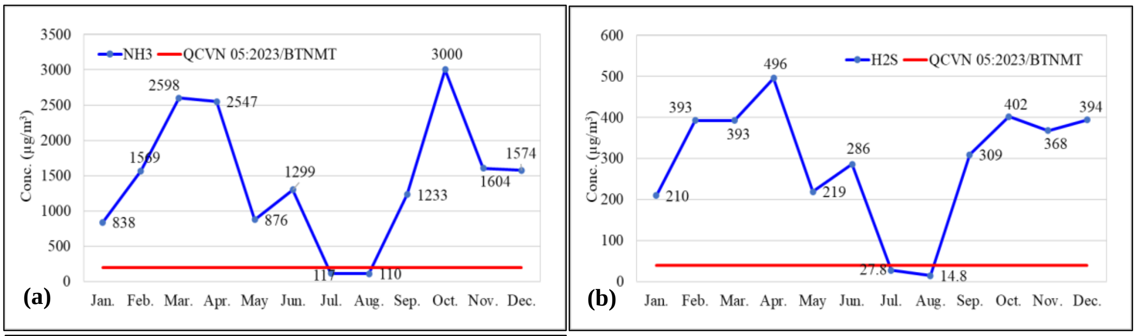


Figure 10. (a) Simulation results of the highest average 1-hour concentration of NH_3 (with KB1); (b) Simulation results of the highest average 1-hour concentration of H_2S (with KB1); (c) Simulation results of the highest average 1-hour concentration of CH_3SH (with KB1).



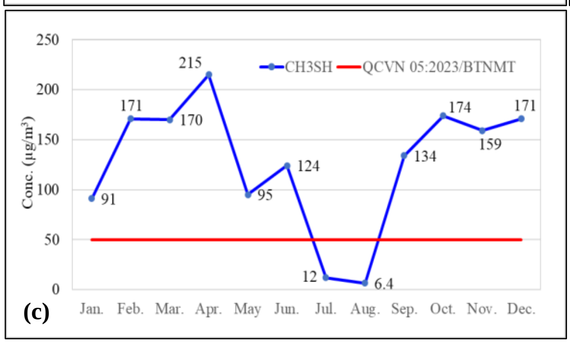


Figure 11. (a) Simulation results of the highest average 1-hour concentration of NH_3 (with KB2); (b) Simulation results of the highest average 1-hour concentration of H_2S (with KB2); (c) Simulation results of the highest average 1-hour concentration of CH_3SH (with KB2).

3.3. Proposed solutions to control odor pollution at Dap Da landfill

Based on the simulation results of the spread of some odor-causing substances using the TAPM - AERMOD system model, it shows that the location of the largest odor and exceeding the QCVN 05:2023/BTNMT standard threshold is inside the landfill adjacent to 2 landfill cells. Although there have been many improvement projects such as: temporary covering of landfill cells; wastewater pumping project; emergency and backup landfill cells, etc. But Dap Da landfill has stopped operating due to overload and pollution. Therefore, proposing some practical measures for the above situation is very necessary.

Management solutions: Synchronously deploy the construction of a system for management, classification, collection, transportation and treatment of domestic solid waste; Build and complete the classification network and strengthen facilities and equipment for classification, collection, transportation and treatment of domestic solid waste for residential areas, production, business and service establishments according to the 3T model (Reduce - Recycle - Reuse); Continue to periodically monitor air quality (odor) in the landfill area and residential areas surrounding the landfill. Continue to invest in additional sanitary landfills at the landfill according to the expansion project until 2050; Disseminate information to people about waste classification at source through (newspapers, internet, television, banners, etc.). In addition, encourage the community to raise awareness about waste (organic, recycled, hazardous). Implement many programs to collect recycled waste in exchange for gifts from the Cao Lanh district natural resources department to raise awareness of waste classification at source; Implement and set short-term and long-term goals for waste collection and treatment in accordance with current regulations.

Technological solutions: Correctly implement the necessary processes in waste treatment to minimize the level of odor pollution to the environment in neighboring areas; Replace outdated treatment technologies with the latest advanced technologies suitable for local budgets; Periodically check machinery and treatment equipment systems, limit incidents of leachate leakage to outside areas; Building a waste incinerator system to generate electricity, however, to bring high efficiency, it is necessary to prepare well in the waste classification stage. In addition, it is necessary to ensure that the incinerator meets the standards according to QCVN on domestic solid waste incinerators to avoid confusion with burning according to separate standards for industrial waste and hazardous waste; Implement shielding measures for corridors inside and outside the landfill. Build a wall around the landfill area combined with planting more isolated trees to minimize odors while creating an environmental landscape that contributes to minimizing the spread of odors to the surrounding environment; Use biological composting and biotechnology measures (using microorganisms to spray to control odors, fix and isolate odor-causing reactions caused by biological reactions); Recycling waste into fertilizer is also applied at the landfill, basically the process of forming and producing fertilizer from domestic waste also causes quite a strong odor. It is necessary to properly manage the stages of odor generation from waste into fertilizer using biological products. Accelerate the project to expand the Dap Da landfill into an advanced solid waste treatment center that does not emit odors into the surrounding environment. Bury, cover with HDPE waterproofing membrane and biological products applied to 2 old landfill cells and 4 expanded landfill cells of the landfill expansion project until 2050. Upgrade the advanced leachate treatment system and gas treatment system to minimize odor pollution and recover CH_4 gas as fuel for the power plant in the future when the landfill scale is expanded. Continue to strengthen monitoring at odor emission locations in the landfill area to create a database to continuously monitor odor emission locations for timely management and treatment measures.

3.4. Safe distance from Dap Da landfill odor

From the results of the odor spread simulation, calculate the minimum odor isolation distance between the Dap Da landfill and the surrounding residential area after applying odor mitigation measures (Table 5, Figure 12).

Table 5. Appropriate odor isolation distance for Dap Da landfill.

Paremeter	Average time	Minimum isolation distance	Appropriate isolation distance
NH_3	1-hour	1.170 m	1.170 m
H_2S	1-hour	1.150 m	
CH_3SH	1-hour	1.170 m	

Figure 12. Simulation of the odor isolation distance of the Dap Da landfill.

4. Conclusion

The study assessed the current status of odor pollution at the Dap Da landfill, showed that the concentration of pollutants exceeded the QCVN 05:2023/BTNMT, concentrated in the area inside the landfill. Calculated the emission load of odoran ts for the landfill (NH_3 is 2,233 kg/year; H_2S is 1,730 kg/year; CH_3SH is 158 kg/year). Combine using of the TAPM-AERMOD system model to simulate the meteorological and diffusion of odorants. The simulation results show that: the average 1-hour concentration of NH_3 ranges from 36.7-1000 $\mu g/m^3$, the area with the average 1-hour concentration of NH_3 ranges from 200-500 $\mu g/m^3$ has the farthest spread distance of 2 km and mainly spread in the Northwest direction; The average 1-hour concentration of H_2S ranges from 4.9-165 $\mu g/m^3$, the area where the average 1-hour concentration of H_2S ranges from 42-80 $\mu g/m^3$ has the farthest spread distance of 2.1 km and mainly spread in the Northwest direction; the average 1-hour concentration of CH_3SH ranges from 2.15-71.8 $\mu g/m^3$, the average 1-hour concentration of CH_3SH ranges from 50-70 $\mu g/m^3$ has the farthest spread distance of 623 m and mainly spread in the Northwest direction. The main spread direction for odorants is to the West and Northwest. The average concentrations 1-hour of NH_3, H_2S, CH_3SH in the landfill area exceed the QCVN 05:2023/BTMT threshold at some times, the spread distance of odorants ranges from 500-1,150 m. The study has built 2 scenarios in the future to meet the landfill expansion project until 2050: KB1 when the pollution concentration increases 1.5 times compared to the current situation, the transmission distance increases by 1.3-1.5 times; KB2 when the pollution concentration increases 2 times compared to the current situation, the transmission distance increases by 3.2-4 times. In addition, the study also proposed necessary, appropriate and effective odor reduction solutions. However, the study was only conducted for some major odorants such as NH_3, H_2S, CH_3SH, while the odor emitted from the landfill is a complex gas mixture and many odorants, this is the basis for further studies to expand the study of more odorants from the Dap Da landfill. At the same time, continue to expand the study of simulation of odor pollution spread from other landfills in the area to compare and evaluate scientifically and fully the reliability of simulation results of odor pollution spread from different landfills to reflect the impact of odors emitted from landfills on the surrounding air environment in particular and the living environment of the community living around the landfill.

Author contribution statement: Conceived and designed the experiments, analysis tools or data; manuscript editing: H.M.D.; Analyzed and interpreted the data, modeled, wrote the draft manuscript: N.T.T.

Acknowledgements: This research is supported by Vietnam National University HoChiMinh City (VNU-HCM) under grant number TX2025-24-01.

Competing interest statement: The authors declare no conflict of interest.

References

1. Sironi, L.C.S.; Centola, P.; DelRosso, R. Massimiliano Il Grande. Odour emission factors for assessment and prediction of Italian MSW landfills odour impact. *Atmos. Environ.* **2005**, *39*, 5387–5394.
2. Ying, D.; Chuanyu, C.; Bin, H.; Yueen, X.; Xuejuan, Z.; Yingxu, C.; Weixiang, W. Characterization and control of odorous gases at a landfill site: A case study in Hangzhou, China. *Waste Manag.* **2012**, *32(2)*, 317–326.
3. Nicolas, J.; Craffe, F.; Romain, A.C. Estimation of odor emission rate from landfill areas using the sniffing team method. *Waste Manag.* **2006**, *26(11)*, 1259–1269.
4. Romain, A.C.; Delva, J.; Nicolas, J. Complementary approaches to measure environmental odours emitted by landfill areas. *Sens. Actuators B* **2008**, *131(1)*, 18–23.
5. Fang, N.Y.J.; Cen, D.Y.; Shao, L.M.; He, P.J. Odor compounds from different sources of landfill: Characterization and source identification. *Waste Manage.* **2012**, *32*, 1401–1410.
6. Lim, J.H.; Cha, J.S.; Kong, B.J.; Baek, S.H. Characterization of odorous gases at landfill site and in surrounding areas. *J. Environ Manage.* **2018**, *206*, 291–303.
7. Lucernoni, L.C.F.; Sironi, S. Comparison of different approaches for the estimation of odour emissions from landfill surfaces. *Waste Manage.* **2017**, *63*, 345–353.
8. El Sersy, A.S.H.I.; Abdelmonem, N.; Elshishini, S.; Ismail, I. Estimation of landfill gases in Egypt, 1-evaluation and validation of different models. *IOP Conf. Ser.: Mater. Sci. Eng.* **2018**, 12008.
9. Sarptaş, S.E.H.; Seyfioğlu, R.; Boyacıoğlu, H.; Dölgen, D.; Alpaslan, N. Models for the prediction of landfill gas potential – A comparison. 2012.
10. Hosseini, S.S.; Yaghmaeian, K.; Yousefi, N.; Mahvi, A.H. Estimation of landfill gas generation in a municipal solid waste disposal site by LandGEM mathematical model. *Global J. Environ. Sci. Manage.* **2018**, *4(4)*, 493–506.
11. Spokas, K.A.; Bogner, J.; Corcoran, M. Modeling landfill CH4 emissions. *Elem. Sci. Anth.* **2021**, *9(1)*, 00050.
12. Thao, M.T.T.; Thang, D.X.; Long, B.T. Research of estimating emission factors of polution gas from landfills (CH_4, H_2S, NH_3, Methyl Mercaptan). *Sci. Technol. Dev.* **2015**, *18(M2)*, 115–125.
13. Tuyen, N.T.K. Applying LandGEM model to evaluate and forecast emissions from Nam Binh Duong solid waste landfill and propose collection and reuse solutions. 2016.
14. Viet, L.V.; Anh, L.H.; Dung, D.D.; Vui, T.V. Simulation of odour dispersion from Da Phuoc landfill. *J. Sci. Technol.* **2017**, *27*, 14–23.
15. Ngan, N.V.C.; Viet, L.H.; Hoang, N.X.; Trung, V.T. Calculation of methane emissions from domestic waste in the inner-city area of Can Tho City. *CTU J. Sc.* **2014**, *31*, 99–105.
16. Tuan, T.N.; Diep, T.T.A. Assessment of CO2e emission reduction of solid waste composting versus landfilling in Hue City. *J. Sci. Technol. Univ. Sci.* **2014**, *1(1)*, 143–150.
17. Minh, T.T.T.; Anh, N.T. Calculating and forecasting methane emission from municipal solid waste disposal for Ha Noi capital. *J. Hydro-Meteorol.* **2017**, *673*, 43–51.
18. Nguyen, N.T.T.; Theu, P.Q. A calculation of methane emission potential from Nam Son landfill, Hanoi. *J. Water Resour. Environ. Eng.* **2019**, *65*, 17–25.

19. Anh, H.Q.; Hung, L.V.; Cuong, T.T.; Lieu, N.T. Estimation of methane emissions at some landfills in Viet nam using developed parameters. *J. Clim. Change Sci.* **2024**, *32*, 1–9.
20. Asadollahfardi, G.; Mazinani, S.; Asadi, M.; Mirmohammadi, M. Mathematical and experimental study of hydrogen sulfide concentrations in the Kahrizak landfill, Tehran, Iran. *Environ. Eng. Res.* **2019**, *24(4)*, 572–581.
21. Talaiekhozani, A.; Nematzadeh, S.; Eskandari, Z.; Dehkordi, A.A.; Shahabaldin, R. Gaseous emissions of landfill and modeling of their dispersion in the atmosphere of Shahrekord, Iran. *Urban Clim.* **2018**, *24*, 852–862.
22. Saral, A.; Demir, S.; Yildiz, S. Assessment of odorous VOCs released from a main MSW landfill site in Istanbul-Turkey via a modelling approach. *J. Hazard. Mater.* **2009**, *168(1)*, 338–345.
23. Kanabkaew, T.; Rakmak, N.; Choosaeng, S. Assessment of hydrogen sulfide dispersion from dumpsite using AERMOD modeling system. *Adv. Mater. Res.* **2014**, *931-932*, 650–654.
24. Liu, Y.; Lu, W.; Wang, H.; Huang, Q.; Gao, X. Odor impact assessment of trace sulfur compounds from working faces of landfills in Beijing, China. *J. Environ. Manage.* **2018**, *220*, 136–141.
25. He, H.; Wu, T.; Xu, H.; Lu, Y.; Qiu, Z.; Wang, X.; Zhang, P. Investigation on the emission and diffusion of hydrogen sulfide during landfill operations: A case study in Shenzhen. *Sustainability* **2021**, *13*, 2886.
26. Szałata, Ł.; Zwoździak, J.; Majerník, M.; Cierniak-Emerych, A.; Jarossová, M.A.; Dziuba, S.; Knošková, Ľ.; Drábik, P. Assessment of the odour quality of the air surrounding a landfill site: A case study. *Sustainability* **2021**, *13*, 1713.
27. Wijaya, S.P.; Ainun, S.; Permadi, D.A. Methane emission estimation and dispersion modeling for a landfill in West Java, Indonesia. *J. Civil Eng. Forum.* **2021**, *7(3)*, 239–252.
28. Palmiotto, M.; Fattore, E.; Paiano, V.; Celeste, G.; Colombo, A.; Davoli, E. Influence of a municipal solid waste landfill in the surrounding environment: toxicological risk and odor nuisance effects. *Environ Int.* 2**014**, *68*, 16–24.
29. Cheng, Z.; Sun, Z.; Zhu, S.; Lou, Z.; Zhu, N.; Feng, L. The identification and health risk assessment of odor emissions from waste landfilling and composting. *Sci. Total Environ.* **2019**, *649*, 1038–1044.
30. Zhang, Y.; Ning, X.; Li, Y.; Wang, J.; Cui, H.; Meng, J.; Teng, C.; Wang, G.; Shang, X. Impact assessment of odor nuisance, health risk and variation originating from the landfill surface. *Waste Manage.* **2021**, *126*, 771–780.
31. Thao, M.T.T. Research on the development of emission coefficients of pollutant gases from domestic solid waste landfills under Vietnamese conditions (CH_4, H_2S, NH_3, Methyl Mercaptan). PhD Thesis, Institute for Environment and Resources, VNU-HCMC. 2019.
32. Bui, L.T.; Nguyen, P.H. Integrated model for methane emission and dispersion assessment from landfills: A case study of Ho Chi Minh City, Vietnam. *Sci. Total Environ.* **2020**, *738*, 139865.
33. Dung, H.M.; Bao, N.Q.; Son, N.T. Application of modelling tools for air quality management in Giao Long industrial zone, Ben Tre province, Vietnam. *Environ. Asia* **2023**, *16(3)*, 104–116.
34. Dung, H.M.; An, T.C.; Tam, N.T. Study on air quality management by using model tools in Phu My 2 and Phu My 2 expanded industrial parks, Ba Ria - Vung Tau province. *J. Hydro-Meteorol.* **2024**, *763*, 78–91.

35. Dung, M.H.; Nguyen, T.Q.; Bui, H.M. Modelling air pollution from steel plants and determining the safety distance for the surrounding area in Phu My Town, Ba Ria - Vung Tau Province, Vietnam. *Pol. J. Environ. Stud.* **2025**, *34(1)*, 695–703.
36. Khue, V.H.N.; Thanh, P.T.N.; Bang, H.Q.; Tam, N.T.; Hang, N.T.T. Air emission inventory and application TAPM-AERMOD models to study air quality from 34 ports in Ho Chi Minh City. *Sci. Technol. Dev. J.: Sci. Earth Environ.* **2018**, *2(2)*, 97–106.
37. Dung, H.M.; Bang, H.Q.; Thang, L.V. Evaluate of air pollution dispersion and propose planing scenerios to reduce air pollution for livestock activities in Tan Thanh district, Ba Ria – Vung Tau province. *Sci. Technol. Dev. J.: Sci. Earth Environ.* **2018**, *2(2)*, 26–37.
38. Ruth, J.H. Odor thresholds and irritation levels of several chemical substances: A review. *Am. Ind. Hyg. Assoc. J.* **1986**, *47(3)*, A142-51.