Impact of Odor from a Landfill Site on Surrounding Areas: A Case Study in Ho Chi Minh City, Vietnam

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ABSTRACT

Airborne and odor pollutions generated from landfill operations can adversely affect human health and social well-being. These pollutants should be thus controlled and regulated. Further, the dispersion of odors in the areas surrounding landfills can create public complaints regarding air quality and can increase social tension. Therefore, in this context, we investigated the odor emission from a landfill in surrounding areas using a combination of measuring odor concentrations and conducting a questionnaire survey. The odor measured in three areas, namely, 1, 2, and 3 were at a distance of 1.5 km, 8.2 km, and 10 km from the landfill site, respectively. Results show that the level of odor concentration in area 1 is much higher than the acceptance level of 10-15 ou/m^3 with a mean value of 109.75±39.46 ou/m^3. Odor concentration levels detected 8.2 km and 10 km from the landfill were 18.97±10.84 ou/m^3 and 10.97±10.50 ou/m^3, respectively. Additionally, odor concentration and people's perception of odor varied with geography. This study provides useful information for the management of odor from the Municipal Solid Waste (MSW) management facility in a developing country like Vietnam. Policymakers should consider public perception when framing regulations or making decisions about MSW facilities that also ensure environmental protection.

1. INTRODUCTION

Odor emissions can cause olfactory annoyance. Industries such as treatment plants for water and wastewater, food production facilities, waste disposal operations, and intensive farming activities generally emit odors that are also volatile organic compounds (VOCs). The majority of pollutants from these sources are VOCs, and they cause odor episodes at varying levels of annoyance (Gallego et al., 2008). Industries have an environmental and social obligation to ensure that their intended performance does not harm their surroundings (Parcsi et al., 2012), as detectable odors may influence daily moods and impact both psychology and physiology in individuals (Gallego et al., 2008; Ko et al., 2015). Odors are typically known as contaminants and are subject to specific environmental regulations (Nicell, 2009). Nuisances associated with odor pollution have been one of the most common public complaints to authorities regarding air quality (Hayes et al., 2014; Henshaw et al., 2006), and have become a larger social issue in developed countries (Blumberg and Sasson, 2001; Ranzato et al., 2012). Monitoring tools are necessary to prevent, manage, and mitigate odor impact in communities (Ranzato et al., 2012).

The influence of odors is a combination of interactive variables known as FIDOL: Odor frequency (F), perceived odor intensity (I), odor duration (D), offensive odors (O), and perceived odor location (L). The FIDOL factors encompass both odor patterns and the environment (Freeman and Cudmore, 2002; Nicell, 2009). An annoyance can be quantified, and there is a propensity of an odor to cause a disturbance within a population if it is exposed to an odor intermittently. The intensity of a perceived level of odor annoyance depends not only on odor quality but also on its perceived offensiveness (UK Environment Agency, 2002). Odor pollution is most disturbing when there is more industrial activity near residential areas (Capelli et al., 2011).

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A training process for evaluators (panelists), according to VDI (2006) (VDI- Association of German Engineers), may be used to perform odor assessment studies on a direct basis. In certain parts of Europe and the USA, this approach is now widespread. However, it is time-consuming, costly, and depends largely on local weather conditions (Naddeo et al., 2012; Zarra et al., 2011). An analysis of air quality related to odor perception can be conducted by using a questionnaire survey for the population affected by the odor source. Odor exposure is typically a human experience, so it can be beneficial to study a community for the purposes of odor evaluation (Capelli et al., 2013). A questionnaire assessment can be used to test community irritation levels from all odor sources. The findings of this assessment can be used to identify the origins of odor according to the accumulated stress in a community. This approach is limited to areas where there is an adequate population density to produce statistically significant results (New Zealand Ministry for the Environment, 2016).

The primary perception of public risks faced by residents living near a waste treatment facility is concerns about health issues, deterioration of environmental quality (pollution, dust, noise, odor), increased risk of technical incidents, damage from natural disasters, and devaluation of neighboring property. These concerns are heightened when residents are in close vicinity to the facility (Al-Khatib et al., 2014; Al-Yaqout et al., 2002; Giusti, 2009; Laner et al., 2009; Sankoh et al., 2013; Srangsriwong et al., 2019). The proximity of residents to a planned or current facility appears to be the most significant factors for influencing the residential perception. Many studies have shown that health problems are related to the proximity or exposure to sites (Sever, 1997; Vrijheid, 2000): the closer residents are to the sites, the more likely they are to worry about their adverse effects (De Feo et al., 2013; Furuseth and Johnson, 1988; Rahardyan et al., 2004). Among the anxiety, odor annoyance for those who live near the waste treatment center is considered to be the most directly perceived response. Thus, there is some correlation between proximity and odor annoyance (Aatamila et al., 2011).

In addition, previous studies only investigated the short distance of the odor effect. Particularly, a study in Canada investigated the perception of odor from an area that included a composting plant and a large landfill site. The study involved recruitment and training of 43 residents living adjacent to the site to make odor observations (Héroux et al., 2004). The observations of residents confirmed an impact radius of 1.5 km from the composting zone center. The area beyond 1.5 km was not covered in the study, and no maximum distance was identified. In a study in Germany, trained panelists have found that the relative frequency of odor annoyance ranged from less than 10 to 30% at a distance of 870 m from large composting plants (Albrecht et al., 2008; Fischer et al., 2008). In South Korea, a study investigated the concentration level and variation of odorous gases at the landfill site and in nearby areas within a radius of 5 km from the site. In most surrounding areas, offensive odor was not a significant pollution issue, with the exception of the high generation of the strong odour compounds such as acetaldehyde and propionaldehydes, within a 5 km radius of the site (Lim et al., 2018). In these studies, the levels of odor annoyance were not reported for longer distances. In Vietnam, however, a previous study indicated that areas surrounding Da Phuoc landfill in Ho Chi Minh City (HCMC) were under affected by odor levels, particularly in urban areas within 7 km from waste treatment facility (Tran et al., 2019). Therefore, the purpose of this research was to measure the odor concentration in affected areas in comparison with questionnaire survey results. The obtained results can help enhance environmental protection.

2. METHODOLOGY

2.1 Climate condition of survey area

The survey area is subject to tropical monsoons along with two traditional weather patterns that directly affect odor distribution. The first pattern is the high temperature in two separate seasons: the dry season between November and April, and the rainy season between May and October. The second pattern is the direction of the wind, which changes monthly: (i) from Jan to May in the South (S) or Southeast (SE) direction; (ii) from June to September in the West (W) or Southwest (SW) direction; (iii) from October to December in the Northeast (NE) direction (Tran et al., 2019). The windrose plot of the study area by each quarter for 2019 is shown in Figure 1. As seen in this figure, the wind direction of the survey location was SE from January to March, SW or SE from April to June, SW from July to September, and NE or Northwest (NW) or SE from October to December.

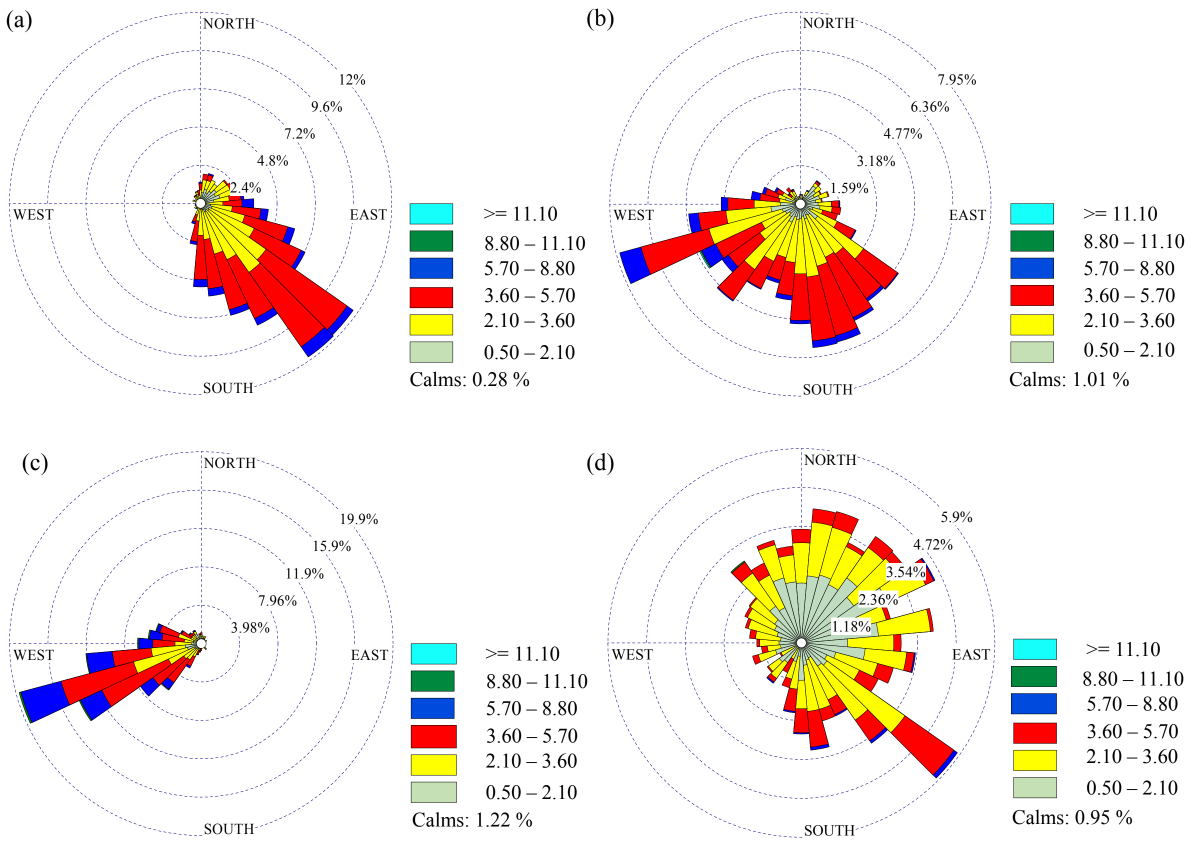

Figure 1. Windrose plot for study area in 2019: (a) From January to March; (b) From April to June; (c) From July to September; (d) From October to December. (Source: prepared from VVTS met data)

2.2 Survey location

2.2.1 Characteristics of MSW treatment facility

The Da Phuoc MSW management facility in HCMC was chosen as the target area for our study. This facility is the primary solid waste management facility in HCMC, and was established in 2007. It has the capacity to treat 5,200 tons of solid waste per day, and mostly relies on landfilling. Since the operation of this facility began, it has received around 22.8 Mt of solid waste. Even though this facility plays a vital role in reducing the substantial waste problem of this city, it causes pollution and odor that spreads to nearby residential areas and to its management areas. There have been more than 500 complaints received from residents living in urban areas approximately 7 km away from the landfill site. Surrounding residents have complained that they are unable to get fresh air inside their apartments. However, the response from authorities has not satisfied these residents.

2.2.2 Site description

Three areas were selected for our investigation zone, which was located in the center of the site with a radius of approximately 10 km (Figure 2). Table 1 show the characteristics of three sampling sites. Regions were classified as Areas 1, 2, and 3 based on odor reports provided by the environmental agency. The survey locations chosen were the same as a previous investigation (Tran et al., 2019) in order to provide consistent reporting and allow for comparative analysis. Area 1 is associated with a high exposure to odor, and it is located in a rural region. Areas 2 and 3 are associated with a high sensitivity to odor impact, and they are located in an urban area.

2.3 Structure of the questionnaire

The questionnaire survey consisted of face-to-face interviews with residents surrounding the MSW treatment facility. The questionnaire aimed to evaluate respondents' perception of odor and attitude toward the MSW treatment facility. It consisted of four components. The first component addressed demographics (gender, age, years of living in the current address). The second component investigated odor perception (frequency, intensity, duration, offensiveness of odors, and factors affecting odors) and included questions regarding the "time of day" and "time of year" that odors are perceived. The third component explored respondents' health issues related to odor impacts. It included the following aspects:

"concern about odors"; "respondent's odor-affected health"; "health symptoms" associated with odors (such as headache, cough, nausea, sleep problems, shortness breath, stuffy nose, anxiety, feeling unhappy and depressed and pain in the heart), and the final component was concerned with odor annoyance, odor issue management, and general attitude towards the MSW treatment facility.

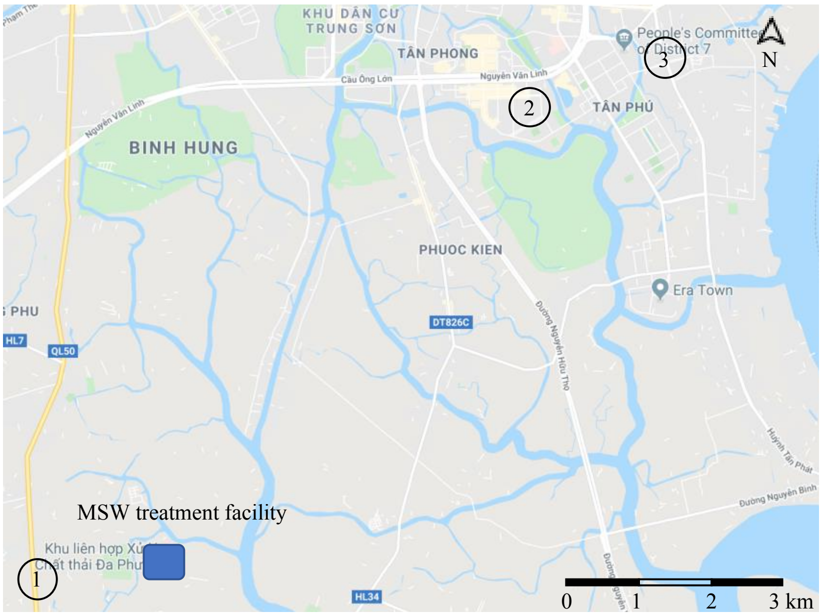

Figure 2. Survey location (Source: google map)

Table 1. Characteristics of sampling sites

	Area 1	Area 2	Area 3
Location	10°40'3.30"N 106°39'4.82"E	10°43'31.28"N 106°42'45.02"E	10°43'54.72"N 106°43'45.35"E
Altitude (above sea level)		Approximately a similar altitude	
Distance from the landfill	1.5 km	8.2 km	10.0 km
Type of land use	Suburban	Residential	Residential
Temperature (average annual)	26.6°C	27.0°C	27.0°c
Rainfall (annual)	1,400-1,700 mm	1,400-1,700 mm	1,400-1,700 mm
Humidity (average annual)	79.5%	80.0%	80.0%
Wind direction		S or SE (Jan-May) W or SW (Jun-Sep) NE (Oct-Dec)	

2.4 Data collection and processing

An odor level indicator XP-329III (New Cosmos Electric Co. Ltd.) was utilized to measure odor concentrations. The method for data collection entailed field sampling monitoring of sensitive receivers at each location within a radius of 10 km from the center of the landfill site. The readings were recorded for 10 min at each sampling area: 20 observations were recorded from area 1 on Sep 20th, 2019; 30 observations were recorded for area 2 on Sep 16th, 2019, and 41 observations were obtained from area 3 on Sep 17th, 2019. Meteorological data such as wind speed, wind direction, humidity, and temperature were collected during the odor concentration measurement. Data on wind speed and wind direction were collected from met station VVTS (Tan Son Nhat international airport) which is provided by BREEZE Software. The windrose map was prepared by using WRPLOT View software, which is freely available on the website of Lake Environment.

3. RESULTS AND DISCUSSION

3.1 Odor measurements

In area 1, the odor concentration ranged from 49 to 149 ou/m^3 with a mean value of 109.75±39.46 ou/m^3. This area is located 1.5 km from the landfill site. The measured levels of odor concentration and the windrose plot for this area are shown in Figure 3. From this data, we can see that the odor concentration in area 1 was more than 7 times the acceptable level of 10-15 ou/m^3, which is the level specified by the Offensive Odor Control Law (Japan Ministry of the Environment, 2003). The rapid industrial expansion and urbanization of Japan during 1960s resulted in a mounting number of complaints related to air pollution, noise, and offensive odors. To tackle this chronic issue, the "Offensive Odor Control Law" was introduced in 1972. Since its inception, the regulation has helped reduce the number of offensive-odor related complaints dramatically. The odor levels in area 1 are consistent with the perception of the population that was surveyed, where the majority of the respondents (more than 55.0%) reported high odor nuisance levels. This is likely because the area is very close to the MSW treatment facility and is also located on the upwind side of the facility, as seen in Figure 2. However, the surrounding regions of the MSW treatment facility are profoundly affected by odor pollution regardless of the direction of the wind, a finding which is supported by previous studies (Badach et al., 2018; Che et al., 2013; Srangsriwong et al., 2019).

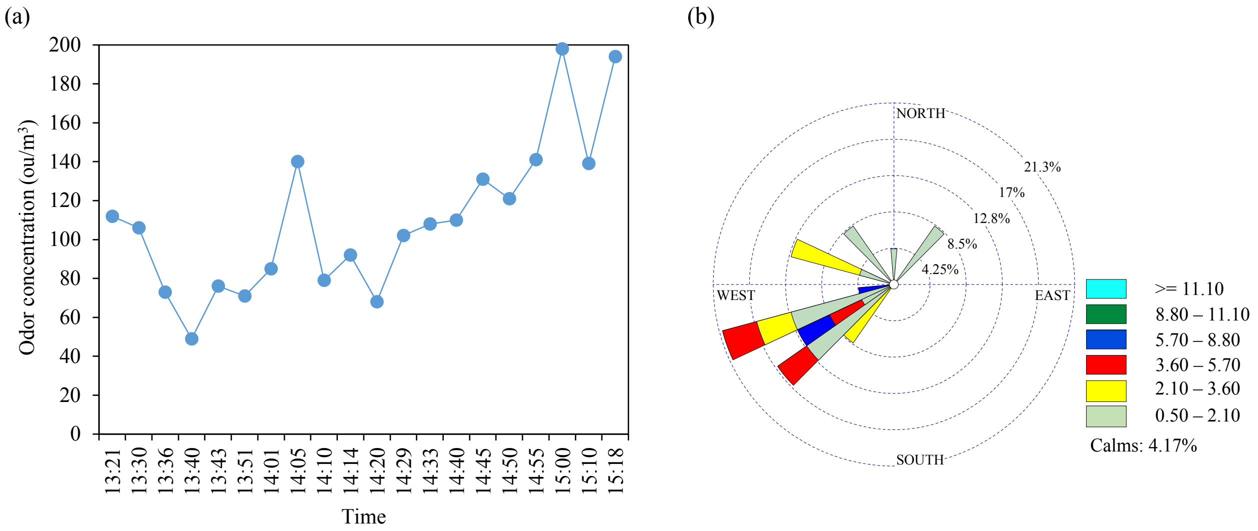

Figure 3. (a) Odor concentration; (b) Windrose plot for area 1 of Sep 20th, 2019 (Source: prepared from field survey 2019)

In area 2, which is located 8.2 km away from the facility, the odor concentration ranged between 2 and 44 ou/m^3 with a mean value of 18.97±10.84 ou/m^3. Figure 4 shows the results of odor concentration and the windrose plot for this area. In this area, the odor concentration is also above the acceptable limit for residential areas (Japan Ministry of the Environment, 2003). It is important to note that this area is a residential area, and is located in the southwest (SW) wind direction (Figure 2). This is a novel finding because this area is located more than 8 km from the MSW treatment plant, and people still reported odor nuisance here (almost 80.0% of respondents reported odor annoyance). However, this could be explained by the social demographics of respondents since odor perception is profoundly influenced by individual differences such as gender, age, and occupation (Bliss et al., 1996; Dalton, 1996).

In area 3, the odor concentration ranged from 1 to 40 ou m^{-3} with a mean value of 10.97±10.50 ou/m^3. The results of odor concentration and windrose plot for this area are shown in Figure 5. This area is located 10 km from the MSW plant, and includes approximately 86.0% of the respondents who reported odor nuisance in this survey. Area 3 is the sector with the highest perceived threat by odor emission from the MSW facility, and it exhibited the highest odor annoyance level in the survey. However, the average odor concentration in area 3 did not exceed the acceptable limit. When examining our monitoring data, we found that the maximum odor concentration here was 40 ou/m^3. From Figure 5, it is apparent that the odor concentration was highest during the period 18:00-19:00, i.e., 6 to 7 pm. This supports the results of the perception survey, where the majority of respondents claimed that odor nuisance was highest from 18:00-24:00, i.e., 6 pm to 12 am the next day (Figure 8). It should be noted that this is in good agreement with wind direction as seen in Figure 6 which shows the windrose plot for area 3 during the evening time for September 2019. It is apparent that Southwest was the predominant wind direction during the evening time of September 2019, with a frequency of 57.0%. Moreover, in area 3, there are human activities such as development of infrastructure and high-rise buildings, which would affect the dispersion.

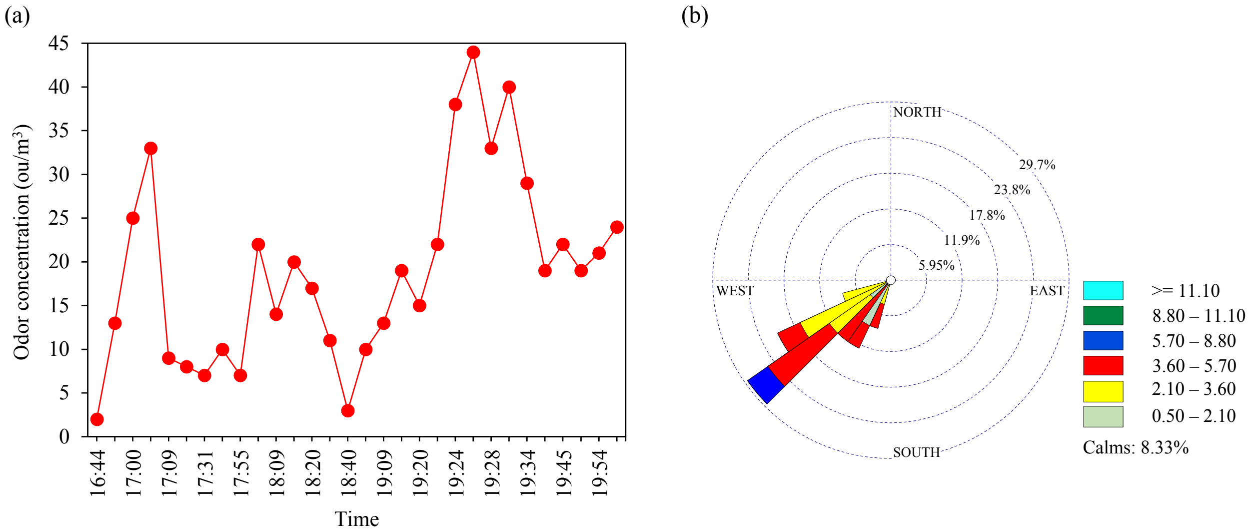

Figure 4. (a) Odor concentration; (b) Windrose plot for area 2 of Sep 16th, 2019 (Source: prepared from field survey 2019)

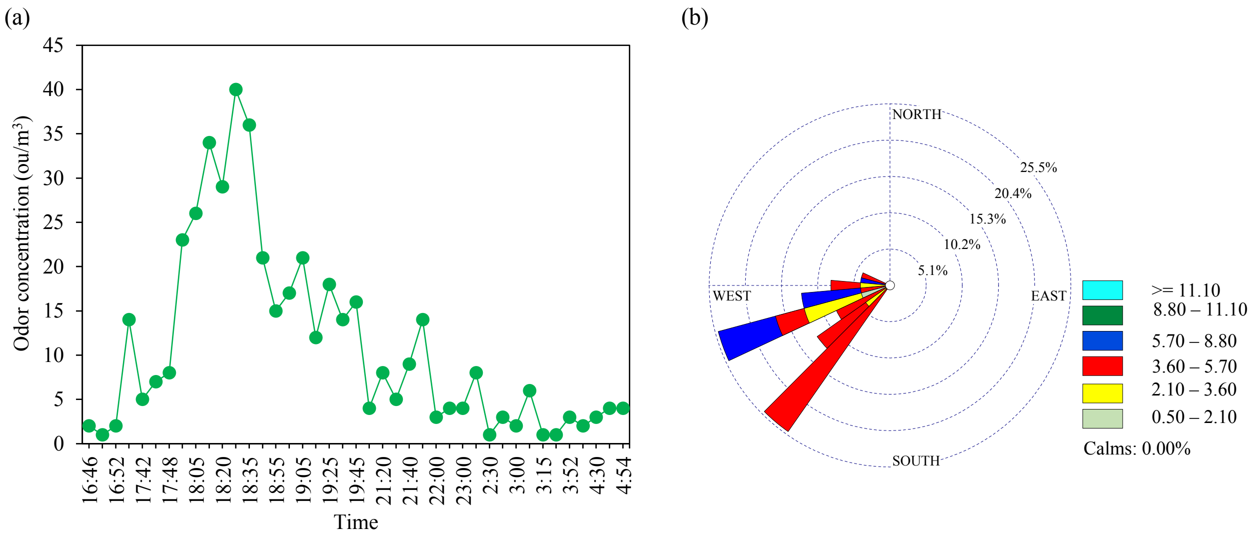

Figure 5. (a) Odor concentration; (b) Windrose plot for area 3 of Sep 17th, 2019 (Source: prepared from field survey 2019)

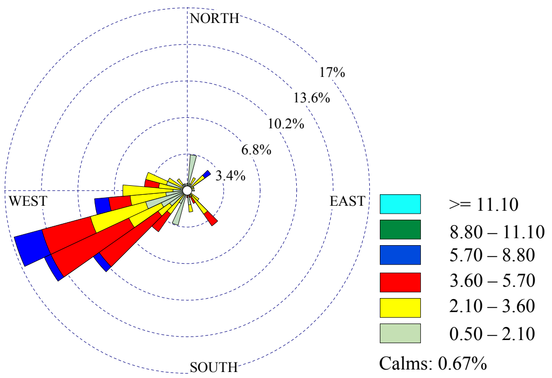

Figure 6. Windrose plot of area 3 in the evening time for Sep 2019 (Source: prepared from field survey 2019)

Figure 7 shows the difference in odor concentration in each area. It is clear that odor concentration decreases by distance. This finding is consistent with Gębicki et al. (2016), which determined that the odor concentration from the municipal landfill in Gda. sk, Poland ranged from 12.50 to 36.70 ou/m^3 along the north-east direction. Furthermore, other research has indicated that the spatial distribution of odor concentration from the municipal wastewater treatment plant in Poland was higher in the vicinity of the facility (Barczak and Kulig, 2016).

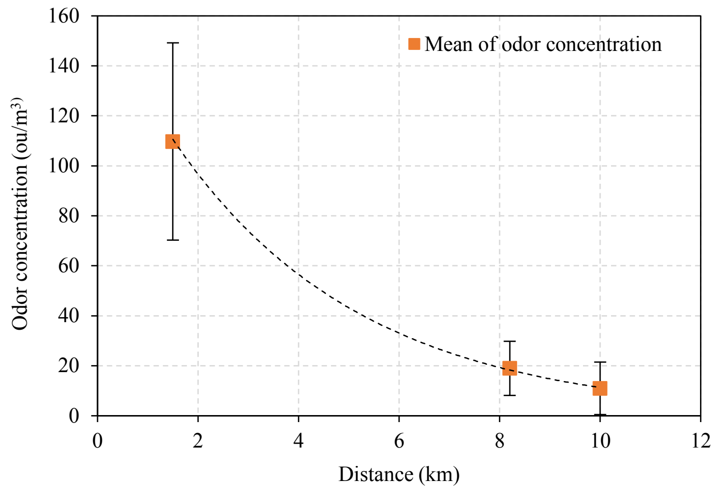

Figure 7. Odor concentration in each area (Source: field survey 2019)

3.2 Summary of community survey results

For a population of 76,602 inhabitants within the investigation area, a minimum number of 409 questionnaires were calculated and applied. Approximately 50.6% of the inhabitants studied were male and 49.4% were female. Further, 85.0% of the inhabitants were over the age of 30 years old. Questionnaire data, which dealt with the perception of odor (i.e., frequency, duration, level, and characteristic), is summarized in Table 2. The responses were classified according to a Likert scale; they were categorized as "not at all, a little bit, moderately, very, and extremely". In terms of response-related odor annoyance, if the response indicated that the person was "very annoyed" or "extremely annoyed," the answer was counted as "percent at-least annoyed" (Freeman and Cudmore, 2002).

Table 2. Results of odor perception by studied area (source: field survey 2018)

	Frequency	Duration	Level	Characteristic
<3 km	92.7% at least once a week	61.0% at least 1-4 h	64.6% at least annoyed	98.8% offensive
3-5 km	91.4% at least once a week	64.3% at least 1-4 h	45.7% at least annoyed	94.3% offensive
5-7 km	58.9% at least once a week	63.6% at least 1-4 h	77.7% at least annoyed	95.5% offensive
>7 km	76.6% at least once a week	54.5% at least 14 h	85.5% at least annoyed	93.8% offensive

The results of the community survey indicate that the odor impact was influenced by wind direction and seasonal change in the area investigated. The observed wind directions were 62.1%, 5.9%, and 1.2% corresponding to Southwest, West wind, and calm hour, respectively (Figure 1(c)). It is implied that the high concentration of odor dispersion probably occurred in the downwind side of the facility. As a result, nearly 46.2% of respondents perceived bad odors between June and August, followed by 33.0% of respondents from September to December. This finding is supported by previous works (Damuchali and Guo, 2020; Palmiotto et al., 2014), which have discovered the high concentrations of air pollutants downwind of the emission source. As seen in Table 2, the area of less than 3 km from the facility exhibited a high perception of odor frequency (i.e., 92.7% at least once a week). In other words, this area has high exposure to odor effects. It is also noteworthy that odors are continuously produced by the MSW facility, as odors in four areas were perceived for multiple hours daily. The majority of respondents reported that the odor from the MSW facility was offensive, and the area of less than 3 km from the facility again had the highest proportion with 98.8% of respondents reporting an offensive odor. Interestingly, the area of more than 7 km from the facility had the highest rate of odor level annoyance (85.5%). Nausea, shortness of breath, and feelings of unhappiness and depression were symptoms recorded in the population. Tran et al. (2019) indicated that residents who live more than 5 km away from the MSW facility had severe odor annoyance from June to October and the period of time during which respondents perceived the worst odor is shown in Figure 8. As shown in Figure 8, the majority of respondents perceived odor pollution during a period between 18:00-24:00, i.e., 6 pm to 12 am in the next day. This is consistent with the community results.

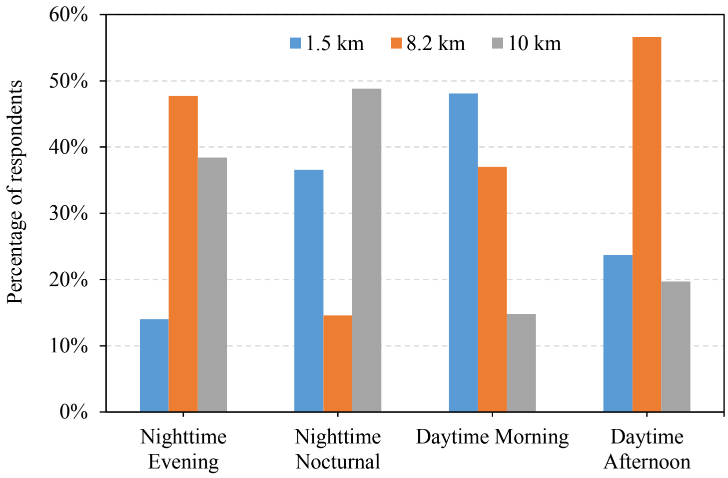

Figure 8. Period of perceived odor (Source: field survey 2018)

Table 3 summarizes the concern, annoyance, and reaction of an area's population that is dealing with odor pollution. The attitude of the populations toward the MSW facility operation is also summarized. The odor level has a strong effect on exposure and annoyance. Areas more than 7 km from the facility again had high proportions of respondents that were concerned and annoyed with odor effects (88.3% very/extremely worried and 85.5% very/extremely annoyed). From this data, it is apparent that most of the respondents in the four areas felt bad/very bad about MSW facility operation. To deal with odor issues, approximately 58.0% of people surveyed close their windows when they detect the odor, while 0.3% (2 out of 409) leave their homes. A proportion of respondents reported odor emissions in their living areas (i.e., informed authorities). From this, it can be inferred that all areas were affected when compared with an acceptable level of cumulative adverse odor effect. The criterion for this acceptable level is that ≤20% of the population are annoyed (Freeman and Cudmore, 2002).

Table 3. Results of community survey by studied area (source: field survey 2018)

	Concern	Annoyance	Reaction	Attitude
<3 km	75.6% very/extremely worried	59.8% very/extremely annoyed	62.2% informed authorities	76.8% bad/very bad
3-5 km	81.4% very/extremely worried	68.6% very/extremely annoyed	45.7% informed authorities	61.4% bad/very bad
5-7 km	75.9% very/extremely worried	71.4% very/extremely annoyed	69.6% informed authorities	88.4% bad/very bad
>7 km	88.3% very/extremely worried	85.5% very/extremely annoyed	60% informed authorities	87.6% bad/very bad

3.3 Comparison between physical condition of odor measurement and community survey results

The mean odor concentration of the three locations and the perceived odor intensity is plotted in Figure 9. As seen in this figure, there was a marked difference between mean odor concentration and intensity of odor perceived. All areas other than area 1 showed a remarkable difference in terms of mean odor concentration and perception of odor intensity. This is likely because odor perception relies on several parameters, such as climatic conditions, subjective consciousness, and the effect of different odors (Davoli et al., 2003; De Gisi et al., 2017; Gallego et al., 2008). Personal perception also is related to other environmental stressors, socioeconomic status, and disruptions in social activity (Nimmermark, 2004; Sucker et al., 2001). Cognitive differences when considering demographics such as age, gender, occupation, and lifestyle habits are regulated further by psychological variables in olfactory perception (Bowler et al., 1996; Davies and Davies, 1999; Doty, 1997; Hayes and Jinks, 2012). Thus, it is important to note that residents with a higher level of education and a higher income level felt more annoyed from lower odor levels. These residents also exhibited greater concern about environmental issues in general.

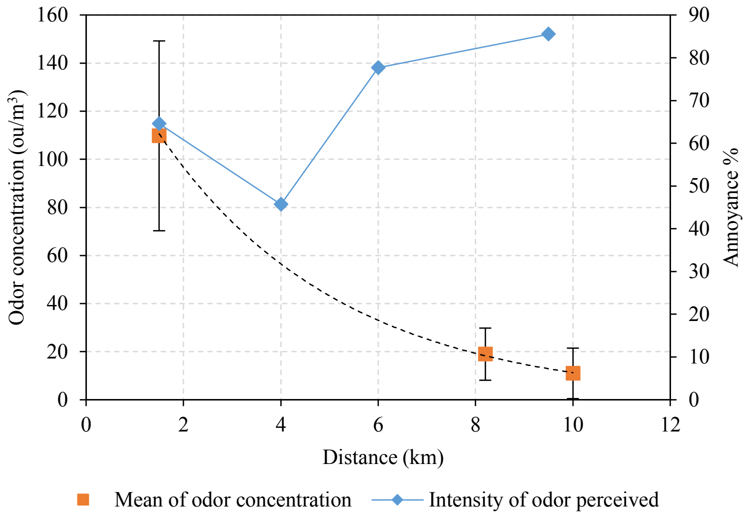

Figure 9. Comparison between odor concentration and odor annoyance (Source: field survey 2018 and 2019)

It is known that intermittent odor exposure may lead to adaptation or sensitivity of individuals, altering their capacity to perceive the odor through physiological changes (Dalton and Dilks, 1997; Press and Minta, 2000). However, because members of the community were exposed continuously to industrial smells, they were accustomed to odors at a peripheral level. When populations were less conscious of odors, their attitudes were more disagreeable and more negative (Dalton and Dilks, 1997). It is possible that people who had lived for less than five years at their current address were more sensitive to odor issues in comparison to those who had lived there for more than ten years.

4. CONCLUSION

In this study, we have investigated the level of odor concentration as well as the perception of odor impact in areas surrounding the MSW treatment plant in HCMC, Vietnam. Specifically, the odor level was measured in three areas, namely, area 1, 2, and 3. Area 1 is 1.5 km upwind, while areas 2 and 3 are downwind of the facility at distances of 8.2 and 10 km, respectively. From the investigation, it was observed that the odor concentration for area 1 was 109.75±39.46 ou/m^3. This is considerably higher than the acceptable level for an area within that radius, 10-15 ou/m^3. As a result, significant odor concentrations were detected in areas downwind of the facility with observed concentration levels in area 2 and 3 reading 18.97±10.84 ou/m^3 and 10.97±10.5 ou/m^3, respectively.

Additionally, odor concentration and respondents' perception of odor varied by geography. This study provides useful information for the management of odor from MSW management facilities in developing countries like Vietnam. Policymakers should consider public perception when developing regulation or making decisions about MSW facilities that also ensure environmental protection. Since there are no clear guidelines on odor management for landfill operations in Vietnam, this research suggests the Japanese Offensive Odor Control Law as a reference for Vietnamese authority. This piece of regulation is a good demonstration of how to deal with offensive odors from business activities for the protection of the living environment and human health. Public participation is a very important aspect of waste management facilities. We also recommend ensuring public consultation towards better landfill management. In addition, as touched upon in this study, socio-demographic parameters such as education level and income also significantly influence odor perception, and this can be explored in future research.

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