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Assessment of odorous VOCs released from a main MSW landfill site in Istanbul-Turkey via a modelling approach

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ABSTRACT

An air pollution modeling study was conducted to investigate the odorous effects of volatile organic compounds (VOCs) emissions from a sanitary landfill area on ambient air quality. The atmospheric dispersion of hydrogen sulfide (H_2S) and 22 VOCs was modeled. Industrial Source Complex v3 Short Term (ISCST3) model was used to estimate hourly concentrations of odorous VOCs over the nearest residential area. Odor thresholds of VOCs of interest were also found in the literature. Results showed that short-term averages of three odorous VOCs, namely ethyl mercaptan, methyl mercaptan and hydrogen sulfide, exceeded their odor thresholds, which are reported to be 0.022, 0.138 and 11.1 $\mu g/m^3$, respectively, at several points within the domain. Their highest concentrations within Gokturk County were estimated to be 0.09387 $\mu g/m^3$ for ethyl mercaptan, 0.07934 $\mu g/m^3$ for methyl mercaptan and 6.315 $\mu g/m^3$ for hydrogen sulfide. Short-term model results revealed the occasional odor problems being reported for Gokturk County. Hourly concentrations were used to obtain frequencies of odor episodes in Gokturk County via a probability analysis. The results showed that ethyl mercaptan concentrations did not exceed its odor threshold during more than 8.84% of the time. Similarly, the maximum odor episode frequencies for methyl mercaptan and hydrogen sulfide were 0.98% and 0.34% of the time, respectively.

1. Introduction

Municipal solid waste (MSW) landfills are potential sources of offensive odors causing annoyance in neighboring urban areas. Therefore, odor pollution has become a growing concern during the last decades for urban communities located near or downwind of MSW landfills. The annoying odors released to the atmosphere from landfills may cause decreased quality of life and possibly more negative consequences on human health and welfare [1]. As a result, odor control has become a key issue facing landfill operation systems both in the management of existing sites and in the process of developing new sites to meet air quality standards in the surrounding areas.

Landfill emissions mostly comprise methane (CH_4), carbon dioxide (CO_2) and hydrogen sulfide (H_2S). They also include some non-methane volatile organic compounds (VOCs). Those VOCs may be mentioned as saturated and unsaturated hydrocarbons, acidic hydrocarbons, organic alcohols, aromatic hydrocarbons, halogenated compounds, sulfur compounds and mercaptans [2]. Zou et al. [3] stated that the number of VOCs released from a landfill may vary between 38 and 60 from winter to summer seasons.

Although the total amounts of those VOCs are usually below 1% (by volume) of the total landfill gas (LFG) emissions, their adverse effects on the environment are not negligible. Some specific groups of VOCs originating from landfill sites are considered to be among the most hazardous air pollutants. Some of them are known to be toxic or carcinogenic [4] such as benzene, benzene ring bearing VOCs, formaldehyde etc. Prolonged exposure to the LFGs containing benzene, toluene, and xylenes (BTX) and chlorinated hydrocarbons can cause severe health problems especially on landfill operators [3]. Their most flagrant property is that they cause offensive odor problems [5,6]. Release of VOCs into the ambient air may significantly reduce air quality and endanger public health and welfare. In addition to human health effects, a range of chlorofluorocarbon compounds arising from landfill sites contribute to both stratospheric ozone depletion and greenhouse effect [7].

Quantity of odorous substances releasing from a source should be defined in such a way that their smelling property can be quantified in order to be able to assess their effects of annoyance in the surrounding atmosphere via a suitable modeling approach. Concentration of odor (or odor threshold, OT) can be measured using dynamic olfactometry which is based on sensory analysis using human nose as a detector. Compared to the human nose, many

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of the chemical detectors are not as sensitive for the odor active compounds [8]. Moreover, some studies attempted to construct correlation between sniffing odor and various odorous VOCs for instrumental quantification of odor concentration [9–11], but no definite results were obtained for a full VOC-to-odor correlation. Therefore, olfactometric method still stands as the unique method for odor definition of VOCs. The method determines how many times an odorous gas sample must be diluted with odor-free air to be just detectable by 50% of the panel. Here, panel is a group of people who are specially selected and trained for odor smelling. The number of required dilutions defines the odor concentration in Odor Units per cubic meter (ou m^{-3}). These tests are carried out in laboratory conditions with panelists [12,13]. Although the olfactometric measurement is time consuming, labor intensive, expensive and is subject to large variation between panelists [14] and laboratories [15], because of the above reasoning, it is accepted as a standard with the protocols described in the CEN (Comite Europeen de Normalisation) standard [16].

Odorous compounds, when released to the atmosphere, undergo the transportation effect of dominant wind in the horizontal direction while dispersion mechanisms also take place in both of the cross-wind directions of vertical and horizontal. All these actions will decrease the concentrations of individual VOCs in the transported plume causing also a decrease in odor concentration. Beyond a distance when odor unit concentration falls just under the odor threshold (OT) limit, there will be no sensible odor in the air which results in no odor problem. Atmospheric dispersion and transportation of odorous VOCs can be modeled by Gaussian Dispersion Model in order to assess the possible odorous effects in the surrounding environment [17]. All sophisticated dispersion models need reasonably accurate emission data. Therefore, elaborate assessment of individual VOCs, both in type and amount, is needed to quantify emissions from a large area source of typically indefinite geometry and with a spatially inhomogeneous surface like a MSW landfill [5].

This study concentrates on the quantification of all possible odorous VOCs releasing from a main MSW landfill (Kemerburgaz–Odayeri) of Istanbul and assesses the annoying odor problem on short-term transportation behavior in the surrounding area of the mentioned MSW landfill.

2. Materials and methods

2.1. Site definition and odor problem

Istanbul is the biggest metropolis of Turkey in economical aspects and is the most attractive city. It has 5712 km^2 surface area. According to the census of 2007, the populations of Istanbul and the whole Turkey are 12,461,170 and 70,586,256, respectively. Istanbul is also the most crowded city of Turkey with the population density of 2420 people/km^2, while overall population density of Turkey is 92 people/km^2 [18]. The city is settled in northwestern part of Turkey where it acts as a bridge between European and Asian parts of Turkey (Fig. 1). 65% of city's total population live in European side, while the rest in Asian side.

According to the recent data, 13,200 tonnes per day of domestic waste is generated in Istanbul. 8700 tonnes of this amount belongs to the European side while the rest 4500 tonnes belongs to the Asian side [19]. There are currently two active MSW landfills operating in Istanbul since 1995. Two closed dump sites in Hasdal and Umraniye had been active till 1995. Of the active landfills, one is located in Kemerburgaz on the European side and the other is located in Şile on the Asian side of Istanbul. These two landfills have been receiving all of the domestic wastes of Istanbul since 1995. Locations of active MSW landfills and closed dumps as well as transfer stations in Istanbul are all shown in Fig. 1.

Due to rapid economic development and urbanization in Istanbul the amount of wastes generated has greatly increased in the last decade. The current 13,200 tonnes per day of domestic waste generation capacity was 4800 tonnes per day in 1996. This increase is, of course, closely related to the population increase since Istanbul has been the center of attraction throughout its history.

Demir [20] listed that the municipal wastes in Istanbul comprise mostly ash, organic materials, paper, plastic, glass, textiles and metals. According to the studies that have been summarized in his study, ash content in wastes has decreased from 29% (wet weight percentage) in 1979 to 7% in 2003. This may be explained by the increasing use of natural gas instead of coal for heating purposes. In contrast, the wet weight percentages of organics and plastics showed a great trend of increase over this period. As obviously seen in his study, waste constituents have markedly changed since 1979. Obviously, these changes in waste constituents are due to changing living styles and habits of the population. As a consequence, these changes in waste constituents have lead to higher generation of organic matter. Barlaz [21] states that municipal wastes comprise 30–50% cellulose, 10–15% lignin, 10–12% hemi cellulose, 10–15% fats and 5–10% proteins on dry weight basis. This, in turn, leads to an increase in the organic emissions from municipal solid wastes.

This study is concentrated on Kemerburgaz–Odayeri MSW landfill site where an odor problem occurs from time to time in the neighboring residential areas. Gokturk County, being located about 4 km southeast of the landfill side (Fig. 1), is the closest residential area which may be subject to the possible odor problem. The aim of this study is to determine which VOC(s) may possibly cause(s) the momentary odor problems in Gokturk.

Modeling domain was chosen to reach 6 km east and 8 km south from the northwest corner of the landfill site which covers 48 km^2 of surface area (upper left frame in Fig. 1). It encloses Gokturk County completely. The authors have decided not to consider the other directions and areas because there are no close residentials in those regions.

2.2. Emission inventory of selected VOCs and database

In the context of this study, 22 VOCs as well as hydrogen sulfide (H_2S) were investigated. The selection of VOCs of concern is based on two criteria. First, the emission factor of a particular VOC should be listed in the literature [22]. Second, the odor threshold (OT) of that VOC should be known prior to the study. OTs of several VOCs were found in Nagata [23]. VOCs that are listed in both literatures were chosen to be modeled for odor assessment.

The emission sources of VOCs are the stacks built inside the landfill for the withdrawal of the LFGs as well as area emissions from the surface of the landfill site. There are 90 gas withdrawal stacks in Kemerburgaz MSW landfill which are almost uniformly distributed over the whole landfill area. All of these gas withdrawal stacks are active and they exhaust landfill gas. Measurements on each of 90 stacks throughout the landfill site have been performed. Gas exit velocities out of each and every stack were measured. Multiplying the velocity out of each stack by the cross-sectional area of that stack, gas flowrate from that stack was calculated. H_2S (ppm), CH_4 (%) and CO_2 (%) concentrations were measured directly. Volumetric flowrates of odorous VOCs were calculated by multiplying related emission factors [22] by the flowrate from each stack.

Due to the fact that Gaussian dispersion equations are based on mass flowrate of individual pollutants instead of volumetric flowrates, the above mentioned procedure was to be completed in order to obtain a suitable data set for the use with Gaussian dispersion equations. For this purpose, volumetric flowrate of each species

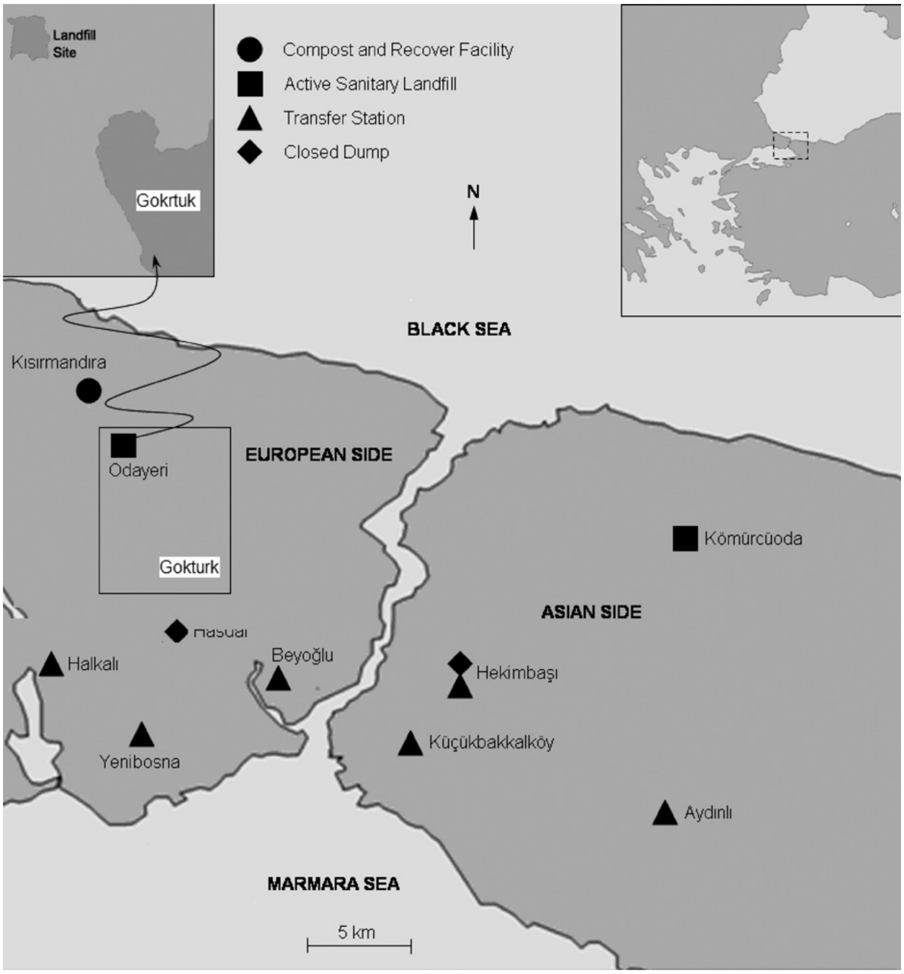

Fig. 1. The locations of municipal solid waste collection, transfer and disposal facilities in Istanbul.

was converted into mass flowrate using ideal gas law as follows:

$$\dot{m}_{ij} = Q_{ij}\frac{P_j M_i}{RT_j} \tag{1}$$

where $\dot{m}_{ij}$ is the mass flowrate of ith species in the jth stack, Q_{ij} is the volumetric flowrate of ith species in the jth stack, P_j is the pressure in the jth stack, M_i is the molar mass of ith species, R is universal gas constant (0.082 atm L/mol K) and T_j is the temperature of stack gas from the jth stack. After calculating mass flowrates of VOCs, area emission rate was also assumed to be the same as total emission rates of stacks [24]. A list of VOCs chosen to be modeled is given in Table 1 along with their odor threshold values and total stack emission rates calculated for Kemerburgaz MSW landfill site.

2.3. Meteorological data

Meteorological data was obtained from the local meteorological station installed in landfill site. Measurements were performed from January 2007 to November 2008. Hourly wind speed and wind direction measurements were recorded and frequencies of occurrences for northwesterly winds, which carry the pollution toward Gokturk, were calculated. The wind rose is given in Fig. 2.

2.4. Topographical conditions

The topographical conditions which are dominant throughout the domain have properties effective on Gaussian Dispersion. Due to the fluctuations in the plume shape, the topographical conditions certainly affect the dispersion. A topographical map of the domain is shown in Fig. 3.

Simple Gaussian Dispersion formulae are not capable of accounting for the effects of these topographical structures. Thus, EPA's software for air pollution modeling named ISC3 (ISCST3) was used for short-term-effects of VOCs released from the landfill site.

2.5. Modeling methodology

The first step of the study involves the short-term (1 h) dispersion model of the 23 pollutants of interest. Measured meteorological data was used in this step. The simulations provided a realistic approach to the case as it was from January 2007 to November 2008.

The following step of the investigation involved a scenario-based short-term model via which hourly maximum concentrations were estimated. Since the spatial concentration distribution and the frequency of odor episodes in Gokturk County depends on the frequency of winds that blow towards Gokturk, and the frequency of these winds are variable, a statistical analysis was considered to be necessary to determine in how much of time the selected VOCs can cause annoying odor problems in Gokturk County. A probability distribution was performed using the results of short-term model run. The short-term model was run for several wind speeds that blow from north northwest (NNW), northwest (NW) and west northwest (WNW) toward Gokturk County, with other meteorological data and emission rates kept constant. In this case, the ambient concentrations of VOCs within Gokturk County were dependent only

Table 1
Odor thresholds and total emission rates of VOCs of interest in Odayeri MSW Landfill.

Odorous compound	Odor threshold values[a]		Total emission rate (10^{-3} g/s)
	ppm	µg/m^3[b]	
Hydrogen sulfide	0.00800	11.1	21.729
Acetone	42.0000	99826	14.511
Acrylonitrile	8.80000	19108	13.286
Butane	1200.00	2854149	11.565
Carbon disulfide	0.21000	654	0.100
Carbon tetrachloride	4.60000	28959	0.000
Carbonyl sulfide	0.05500	135	0.068
Chloroform	3.80000	18566	0.008
Methyl mercaptan	0.00007	0.138	0.273
Ethyl mercaptan	0.00001	0.022	0.323
Ethyl benzene	0.17000	738	1.115
Dimethyl sulfide	0.00300	7.628	1.109
Ethanol	0.52000	980	2.859
m-Xylene	0.04100	178	2.931
Trichloro ethylene	3.90000	20971	0.844
Tetrachloro ethylene	0.77000	5225	1.411
Pentane	1.40000	4133	0.542
Methyl ethyl ketone	0.44000	1298	1.166
Methyl isobuthyl ketone	0.17000	696	30.288
Propane	1200.00	2165166	1.115
Hexane	1.50000	5290	1.292
Dichloro methanol	160.000	556163	2.771
Isopropanol	0.09400	231	6.870

[a] Adapted from Nagata [23].
[b] Under 1 atm at 25 °C.

upon wind speed. The hourly results from several wind speeds were used to determine log-normal fits that explain the data best. The methodology for probability distribution is adapted from Seinfeld and Pandis [25] and is given as follows:

1. From the available meteorological data, it was calculated that the winds toward Gokturk comprise 10.65% of total winds. In order to classify winds of this direction, nine wind speed categories (0.10, 0.35, 0.75, 1.25, 1.75, 2.25, 2.75, 3.50, 5.00 m/s) were identified based on minimum and maximum wind speeds obtained from onsite meteorological station. The number of wind speed categories was optimized between the need for more data points to determine the best log-normal fits and modeling effort. The results from short-term model that use the lowest wind speed would never be used in data fit because of the properties of log-normal curve (the tail of the log-normal curve goes to infinity as the probability goes to 1). The other eight was expected to define a log-normal curve in a reasonable manner.

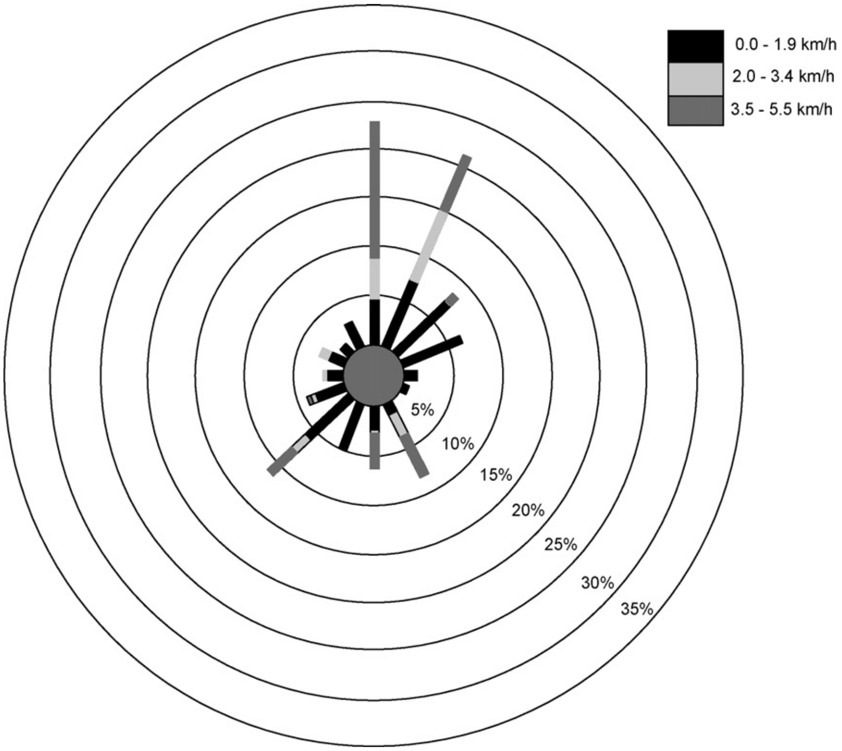

Fig. 2. Wind rose for the domain from January 2007 to November 2008.

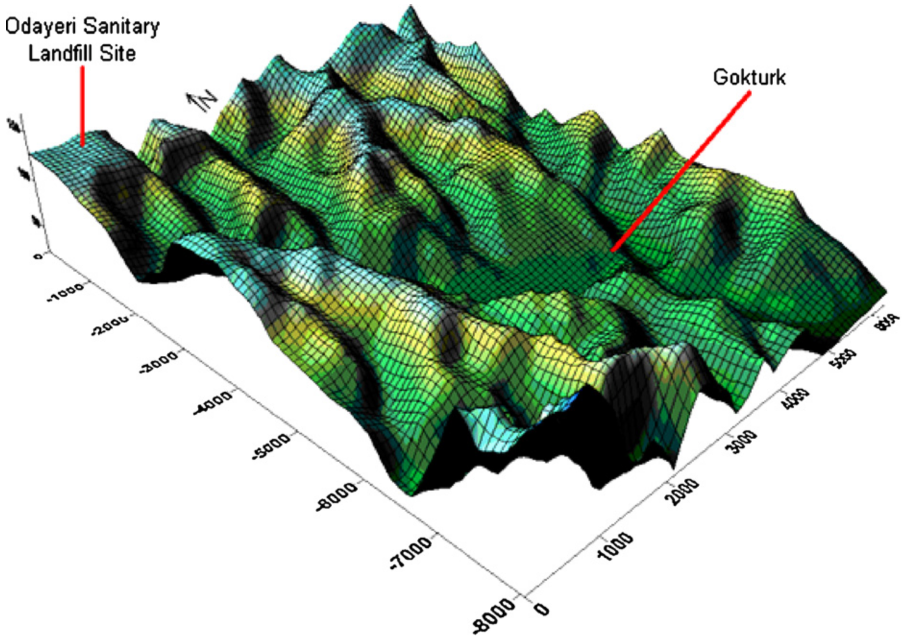

Fig. 3. Topographical map of the modeling domain.

2. As given previously, the frequency of the wind direction (the winds that blow from NNW, NW and WNW toward Gokturk County) that affects the ambient concentrations in Gokturk was 10.65% of the total. This portion of winds was further classified with respect to the selected wind categories. The wind frequencies of selected categories were calculated as follows: Category 1 is 3.0%, Category 2 is 9.20%, Category 3 is 13.00%, Category 4 is 9.50%, Category 5 is 9.10%, Category 6 is 6.40%, Category 7 is 6.50%, Category 8 is 13.10% and Category 9 is 30.20%. These percentages sum up to 100% and all together make up 10.65% of the total winds in the domain.
3. Model runs were performed for each of chosen wind speeds with other meteorological data being kept constant and hourly averages were calculated.
4. It is known that odor problem is momentary, that's why one can or cannot sense the odor once he breathes in. Therefore, odor problem should be identified in a momentary manner. Schauberger et al. [26] assumed this averaging period to be five seconds. The concentration of a species over such an averaging period can be explained by taking into account the concept "peak-to-mean ratio." This ratio is given by Smith [27] as follows:

$$\mathrm{PTM} = \frac{C_\mathrm{p}}{C_\mathrm{m}} = \left(\frac{t_\mathrm{m}}{t_\mathrm{p}}\right)^{\alpha} \qquad (2)$$

where PTM is the peak-to-mean ratio for a specific pollutant, C_p is the peak concentration of the pollutant (averaged over the time period of t_p) and C_m is the mean concentration of that pollutant averaged over the time period of t_m and the exponent α is constant depending on the atmospheric stability class. One gap of this relationship is that it is only valid when the receptor (human nose for the case) is close to the source.

It is obviously expected that PTM decreases over the distance from the source. Mylne and Mason [28] suggested another relationship that takes into account the effect of distance from the source on the value of PTM. They suggested this ratio be calculated using the following formulation:

$$\mathrm{PTM} = 1 + (\mathrm{PTM}_0 - 1)\exp\left[-0.7317\frac{t}{t_\mathrm{L}}\right] \qquad (3)$$

where PTM_0 is the peak-to-mean ratio calculated for those receptors close enough to the source, that's the value calculated by Eq. (2). Here, t is defined as the traveling time of the plume from the source to the receptor and t_L is a measure of t in Lagrangian time scale which can be calculated as follows:

$$t_\mathrm{L} = \frac{0.732kh_\mathrm{r}[\sigma_\mathrm{u}^2 + \sigma_\mathrm{v}^2 + \sigma_\mathrm{w}^2]}{\sigma_\mathrm{w}^3} \qquad (4)$$

where σ_u, σ_v and σ_w are the standard deviations of the wind velocities, k is known as von Karman constant and taken as 0.4 and h_r is the height of the receptor, which can easily be taken as 1.6 m for the case since human nose is the receptor for odor modeling applications.

The hourly ambient concentrations of species of interest were used to calculate the peak-to-mean ratios for the given meteorological conditions and the distance of Gokturk from the landfill site, which is placed between 3500 and 8600 m distances from the source in the wind direction. Although Mylne and Mason [28] states that this relationship is valid up to 1000 m-distance from the source since peak-to-mean ratios with increasing distance converges to unity, peak-to-mean ratios for this case were still calculated for proving purposes using the data peculiar to the study area.

5. Highest peak concentrations of species of interest within Gokturk were selected from the concentration distribution profile for each wind speed category. The resulting peak ambient concentrations within Gokturk formed a concentration matrix whose columns specify the pollutant categories and rows specify wind speed categories.
6. The column vectors of the concentration matrix represent fluctuations in the ambient hourly concentrations of the pollutant of that column with respect to the wind speed. These set of ambient concentrations were, separately, applied to an MS Excel$^\mathrm{TM}$ based computer program developed for determining best log-normal fit that explains the data best. The program was designed to use the Solver Add-in. The data fit program produced one log-normal distribution for each of selected VOC with average concentration and standard deviation.

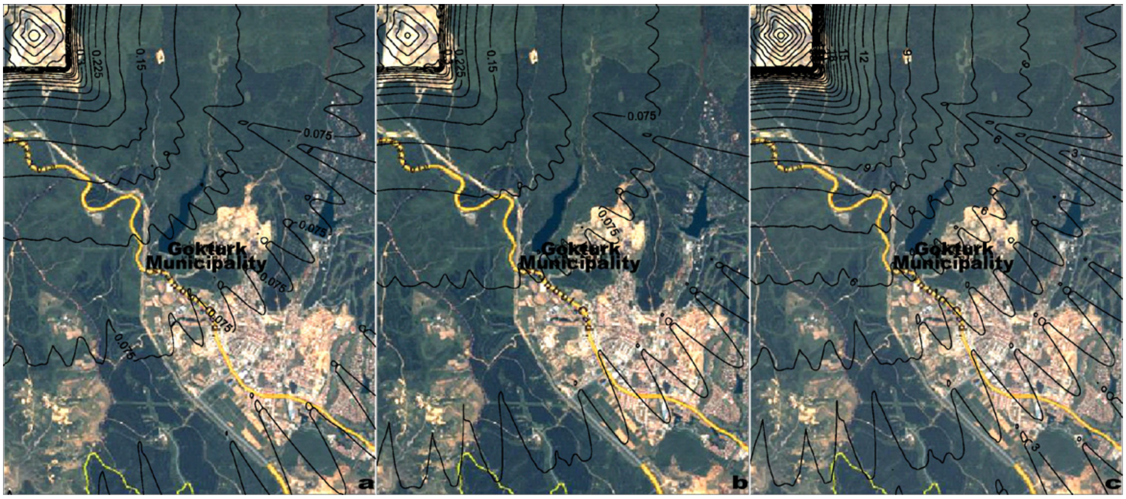

Fig. 4. Hourly dispersion of (a) methyl mercaptan, (b) ethyl mercaptan and (c) hydrogen sulfide (contour values are in μg/m^3).

The absolute values of the error between fitted curves and the data points can be written as

$$E_{ij} = |C_{\mathrm{r},ij} - C_{\mathrm{e},ij}| = |C_{\mathrm{r},ij} - C_{\mathrm{m},j}\exp(z\sigma)| \qquad (5)$$

where E_{ij} is the absolute value of the error between each data point and the value on the best fit corresponding that point, $C_{\mathrm{r},ij}$ is the data point (entry) in the ith row and the jth column of concentration matrix, $C_{\mathrm{m},j}$ is the mean concentration of the current log-normal curve fitted for the jth column in the concentration matrix, $C_{\mathrm{e},ij}$ is the value estimated from the current best fit trial corresponding the data point $C_{\mathrm{r},ij}$, σ is the standard deviation of the current log-normal distribution fitted for the jth column in the concentration matrix. z in Eq. (5) can be calculated iteratively using the following formula after the initialization of Φ and z as $\Phi = 0.5$ and $z = 0$.

$$\frac{\mathrm{d}\Phi}{\mathrm{d}z} = \frac{1}{\sqrt{2\pi}}\exp\left(-\frac{1}{2}z^2\right); \quad -\infty < z < \infty \quad \text{and} \quad 0 \le \Phi \le 1 \qquad (6)$$

where Φ is the cumulative frequency integral as a function of z. The total error for each column of the concentration matrix can then be calculated using the following relationship:

$$E_j^2 = \sum_{i=1}^{m} E_{ij}^2; \quad j = 1, 2, \ldots, n \qquad (7)$$

where E_j^2 is the sum of the individual errors calculated for each jth column member, and m and n are the number of rows and the number of columns in the concentration matrix, respectively.

A constraint based computer program may be used to determine fitted log-normal curves that explain data points the best. The methodology involves the minimization of the total error for each column vector and the individual errors for each element in that column vector. The targets were defined as the mean of the distribution and the standard deviation. The program makes iterations for these variables to minimize the errors previously defined and shows the mean and the standard deviation when the best log-normal curve is reached.

7. Finally, a probability distribution study was performed using average concentrations and standard deviations obtained from the computer program. The frequencies of odor episodes were calculated using the data based on the properties of log-normal distribution. Following, the changes in the frequencies of odor episodes for distinct pollutants were calculated and given in the following paragraphs.

3. Results

Several short-term models were run to determine the effects of VOCs over the nearest residential area, namely Gokturk County. The results were siding with momentary odor complaints. The results from short-term model runs are presented in the following sections.

3.1. Short-term results (real case)

The highest hourly concentrations of VOCs of interest did not exceed their OTs except ethyl mercaptan, methyl mercaptan and hydrogen sulfide. OTs for ethyl mercaptan, methyl mercaptan and hydrogen sulfide were reported to be 0.138, 0.022 and 11.1 μg/m^3, respectively (Nagata, 2003). The highest concentrations estimated for these VOCs were estimated to be 0.549, 0.464 and 36.9 μg/m^3, respectively. However, these highest concentrations fall within the landfill area. The pollutant concentrations, as expected, gradually decreased in the wind direction towards Gokturk county. The highest concentrations *within Gokturk* were found out to be 0.09387 μg/m^3 for ethyl mercaptan, 0.07934 μg/m^3 for methyl mercaptan and 6.315 μg/m^3 for hydrogen sulfide. The pollution maps for these three compounds on 1-h averaging period were shown in Fig. 4a–c.

The hourly concentrations of ethyl mercaptan and methyl mercaptan exceeded their odor thresholds within Gokturk residential area while, for hydrogen sulfide, the concentrations above its thresholds are expected in the upwind region of Gokturk. Hydrogen sulfide is expected to dilute over the pathway from landfill site to Gokturk.

The short-term model involved the calculation of 1-h concentrations, which is the case when the wind blows toward Gokturk. As given before, this is the case during only 10.65% of the total time. It is also known that the hourly concentrations depend not only on the wind direction but also on the wind speed. The best and the worst condition concentrations were, therefore, estimated using a scenario-based model approach.

3.2. Short-term results (scenario-based)

Short-term model results along with the probability analysis were obtained at distinct wind speeds for ethyl mercaptan, methyl mercaptan and hydrogen sulfide following the procedure given in the previous section. The peak-to-mean ratios were calculated using the given meteorological conditions and the distances from the source. The peak-to-mean ratios within Gokturk approached to

Table 2
Ambient concentrations of pollutants causing annoying odors.

Wind speed categories (m/s)	Cumulative wind speed	Hourly concentrations (μg/m^3)		
		Ethyl mercaptan	Methyl mercaptan	Hydrogen sulfide
5.00	0.302	0.02507	0.02120	1.68738
3.50	0.433	0.03573	0.03022	2.40531
2.75	0.498	0.04541	0.03840	3.05639
2.25	0.562	0.05542	0.04687	3.73054
1.75	0.653	0.07111	0.06014	4.78675
1.25	0.748	0.09926	0.08395	6.68187
0.75	0.878	0.13963	0.11809	9.39919
0.35	0.970	0.14821	0.12535	9.97703
0.10	1.000	0.14645	0.12435	9.89744
Average		0.04400	0.03583	2.51834
Standard deviation		0.74300	1.02500	0.79100

unity as the distance from the source increased as in the case in the study of Schauberger et al. [26].

The results as a matrix of peak ambient concentrations of these species within Gokturk were shown in Table 2 (hourly averages and peak concentrations were the same in our case). Each column vector of these matrices shows the fluctuations of peak ambient concentrations associated with the specified odorous pollutant and these sets of data are appropriate for a probability distribution analysis to find out the percentage of time of odor episodes within Gokturk County. For this purpose, as given in detail previously, cumulative wind speed fractions (the second column in the matrix) were used instead of using wind speeds (the first column in the matrix) directly.

A probability distribution analysis was performed for each coupled cumulative wind speed column and concentration column. A log-normal curve was fitted for each coupled data set and the mean concentrations along with standard deviations for each log-normal fit were given in the same table under each associated column.

Using the properties of log-normal distribution, frequencies of occurrences of odor episodes within Gokturk County were calculated. The episodes are calculated as the maximum exceedance times. The results showed that the frequency of odor problems caused by ethyl mercaptan never exceeds 8.84% of the total time period. This means that peaks of ambient ethyl mercaptan concentrations cause annoying odors only 8.84% of the time. Methyl mercaptan, on the other hand, can easily be said not to cause any odor problem. The frequency of occurrence of odor episodes caused by methyl mercaptan was calculated to be 0.98% of the total time. Finally, Hydrogen sulfide was found to be causing any annoying odor problem in Gokturk no more than 0.34% of the total time.

4. Conclusions and discussions

The effects of 22 VOCs and of H_2S on ambient air quality in surrounding areas of one of the main MSW landfill site of Istanbul metropolitan city were investigated using a model approximation. VOCs of interest were selected among those whose odor thresholds were reported in the literature. The emission rates for the selected VOCs were calculated using AP 42 emission factors (US EPA, 1998) along with on-site measurements of flowrates through all stacks in the landfill site. The procedure for the calculation of VOC emission rates are given in Section 2.2. Area emissions were also included in the model and the evaluations were made accordingly. The area emission rate was assumed to be the same as total emission rate from the stacks [24].

Both a real case short-term model and a scenario-based short-term model were run. The real case short-term model results showed that three of these 23 VOCs caused annoying odors from January 2007 to November 2008. These were ethyl mercaptan, methyl mercaptan and hydrogen sulfide. Ethyl mercaptan and methyl mercaptan concentrations exceeded their odor thresholds within Gokturk while ambient concentrations of hydrogen sulfide was higher than its threshold near the landfill site and was lower than its odor threshold within Gokturk.

The results from the scenario-based short-term model run provided hourly concentrations of 23 pollutants of interest with respect to several wind speeds. Peak ambient concentrations of these pollutants were then calculated using these hourly concentrations. Three pollutants, namely ethyl mercaptan, methyl mercaptan and hydrogen sulfide, were selected for the probability analysis, because their peak ambient concentrations within Gokturk were expected to cause annoying odors for several short time periods. The results for these three pollutants were applied to a probability distribution function (log-normal distribution) and frequencies of occurrences for peak concentrations were calculated.

The results from the probability analysis showed that the principal odor component among the 23 pollutants of interest was ethyl mercaptan whose peak concentrations could exceed its odor threshold during 8.84% of the time. Methyl mercaptan and hydrogen sulfide were found practically not to be contributing to the odor problem within Gokturk. Their peak concentrations exceed their odor thresholds during 0.98% and 0.34% of the time, respectively.

These results should also be evaluated in terms of legislative regulations so that whether such facilities should take immediate precautions to prevent the odor problem. Drew et al. [29] summarized the legislative odor standards for some selected countries. It was concluded that two main criteria could be used for the control of odor emissions. One is the odor unit assessment which requires dynamic olfactometric analysis for which some specific numerical standards in odor unit per m^3 were promulgated in some selected countries. The other regulative approach is to constrain the odorous time period for which area measurements should be performed in a time period to determine whether an odor could be sensed or not. The new odor management legislation in Turkey, which has not yet been promulgated, states that the frequencies of odorant time periods should not exceed 15% and 20% of the total measurement period in residential and industrial areas, respectively. The frequency results of this study (8.84% for ethyl mercaptan, 0.98% for methyl mercaptan and 0.34% for hydrogen sulfide) showed less than the allowed odorant time period (15% for residential areas) meaning that there is no need to take further legislative precautions in the MSW area. However, since the hedonic tone of the VOCs originating from MSW landfill areas is very unpleasant, further precautions may be thought to be handled in order to live in more comfortable environment. The following section summarizes part of them.

5. Recommendations

Odorous VOCs in the composition of LFGs are unavoidable and they may cause occasional annoying odor problems in the surrounding area depending upon the wind patterns. Since the odor is noticed immediately, it reveals its effects whenever an air stream carrying odorant VOCs is sniffed by humans. In this sense, the pollution sources of this kind should be handled accordingly by some suitable measures to prevent odorant components from being emitted into the atmosphere, or some other measures should be applied after the emission to the atmosphere. Power generation from LFG is a common method of utilizing valuable LFGs which has roughly 35–50% methane. There is an LFG power generation unit in the Hasdal closed dump (see Fig. 1). Hasdal dump, previously used as wild storing area, has been rehabilitated after 1995, and the project of generating electricity from LFG (35% methane) was launched with 4 MW of power generating capacity. Same type of project was planned to operate for Kemerburgaz–Odayeri MSW landfill area. In this project all active stacks in the landfill area are planned to be collected for power generation. In fact, not all of the 90 stacks will be operated but part of them which are utilizable will be taken into power generation system, or new gas wells may be constructed for a long life operation. The estimated power generation life of the landfill is 20–25 years. This project will both generate power from LFG and also prevent odorant VOCs from being emitted into the atmosphere.

On the other hand, area emissions of odorant VOCs are unavoidable which are capable of causing annoying odors in the surrounding areas depending on wind patterns. A commercial application is also planned for these fugitive emissions to prevent their odor effects. Some types of odor neutralizing solutions are planned to be sprayed over the surrounding atmosphere of the MSW landfill area by means of a suitable number of nozzles. These aerosols will react with odorant VOCs and transform them into non-odorous neutral compounds.

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