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Mitigation of the Odorous Impact of a Waste Landfill Located in a Highly Urbanized Area

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The growing awareness of the impact of environmental conditions on quality of life has led to the consideration of odours as atmospheric contaminants causing "olfactory pollution". Odorous compounds do not directly represent a risk to human health; they are rarely dangerous in nature, not necessarily toxic, and generally found at low concentrations. Nevertheless it has been recognized that exposure to odours may cause different negative effects on human beings, ranging from emotional stress to physical symptoms. Consequently, when a system characterized by high emissions of odours is located in an urban context, its acceptance by the population is affected by its olfactory impact. This paper aims to assess the impact of odorous substances emitted from a landfill on the exposed population, by presenting a specific plant management methodology to minimize exposure to odours in terms of intensity and frequency. The results, evaluated for different percentiles, show that some residential areas may be affected by "olfactory harassment" if specific waste landfill management criteria are not applied. This methodology, if applied during the landfill design phase, may be a major tool for institutional decision-makers for comparing different options when choosing landfill sites.

1. Introduction

In the last few decades, odorous substances have become an environmental concern; before then the interest in odours was related to the study of the sensory system and the sense of smell, or research in the food and cosmetics industries. Only recently have environmental knowledge and available technologies been explored for odour evaluation, therefore increasing the development of specific sampling and odour measurement techniques, (i.e. cryocondensation sampling (Juarez-Galan et al., 2010), adsorptive odour sampling (Boeker et al., 2010), and electronic noses (Bootsma and Milan, 2010)), and the definition of both acceptance criteria and limits for their assessment. Olfactory nuisance is the result of a series of odour perception episodes, which vary from individual to individual. The frequency, duration, intensity, and "character" of such episodes all contribute to the nuisance experience. However, odour emissions are rarely a real danger to human health, and only prolonged exposure to odours may cause discomfort and distress, resulting in olfactory harassment. In consequence, when assessing the environmental impact of production activities, the atmospheric emissions of odorous substances must be considered as they can be the cause of discontent and protests from the communities surrounding the emission sources. In waste disposal systems, odours are related to the microbial degradation processes of putrescible organic substances. These processes develop through complex chains of reactions and produce a multitude of chemical compounds in landfill gaseous emissions. Technologies to control odorous emissions include bio-filters (Sun et al.,

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2000), adsorption on activated carbon (Erto et al., 2010) and scrubbing with an oxidizing solution (Smet et al., 1998), but these technologies are not available to treat very large and diffusive emissions such as those from a waste landfill.

In recent years, landfill gaseous emissions have been chemically characterized (Davoli et al., 2003; Chiriac et al., 2007; Capelli et al., 2011). In particular, Davoli et al. (2003) have quantitatively sampled emissions from distinct landfill surfaces, distinguishing between differently aged wastes and highlighting the differences between "fresh waste" (arriving daily) and "mature waste" (compacted and covered waste sites). In order to measure odour emission from a putrescible waste landfill, two different experimental approaches are available: the first calculates emission values based on atmospheric dispersion models and odour concentrations measured at different locations in a given study area (Sarkar et al. 2003; Nicolas et al. 2006; Drew et al., 2007); the second approach involves local sampling directly on the landfill surface by measuring the odour flow emitted per unit area (Karnink and Parry, 2001; Sironi et al., 2005). The latter approach shows that, in a landfill, surfaces are characterized by three odour emission factors (OEF) as follows:

- An active cell, in which "fresh" waste is heaped daily: OEF $\cong$ 60 o.u./(m^2s);
- Temporarily compacted and covered waste with a thin clay layer: OEF $\cong$ 8 o.u./(m^2s);
- Permanently compacted and covered waste with at least a 1 m-thick clay layer: OEF $\cong$ 4 o.u./(m^2s).

The total emissions of a landfill, calculated as the sum of individual emissions, are consistent with EPA guidelines (US EPA, 1997) and the German guidelines (VDI 3790, 2000), even if odour emissions from the active cell are not considered.

The effect of odour exposure is rather complex because it depends, as already mentioned above, on different variables, such as individual sensitivity, the kind of smell, the frequency at which it is perceived, the intensity and the whole context. Consequently, the literature has not yet defined a unanimous threshold for the emission of odorous substances. In general, exposure thresholds are based on epidemiological evidence and are determined to avoid damage to health; therefore, no regulatory threshold value can define the acceptable level of odour exposure, and identify conditions of olfactory harassment. Therefore, because of their nature, odorous substances are frequently present in compound mixtures, and both the olfactory stimulus and the odour perception are the result of the synergic action of various substances. In order to minimize olfactory nuisance conditions, an IPPC document (IPPC, 2002) suggests different threshold values, according to odour type (hedonic tone) and frequency exposure set to the 98^{th} percentile on an hourly basis. Smells resulting from waste degradation are listed among the most troublesome, because they are very aggressive and their threshold limited to 1.5 o.u./m^3 concentration (on the 98^{th} percentile hourly basis) is specified. This value is taken as a reference in the present study, that focuses on the evaluation of the dispersion of odours from a landfill close to Naples, in an area where several human activities and Sensitive Centres (SC) are located. In particular 3 SC were considered in the area because of their proximity to the landfill and severity of exposure to odours. The dispersion of odours was analysed via using the BREEZE ISCST3 software, developed by the EPA, which enables an assessment of air pollutant dispersion, when the weather conditions and the emitted flow are known. For the analysis, weather data collected at an hourly rate throughout the year 2007 were used, and. in parallel, a piece of software in Visual Basic (FROD-CODE), that enables the evaluation of the frequency of odour exposure and odour contours at a constant frequency, was developed.

2. Modelling of emissions

Atmospheric dispersion models allow the assessment of the concentration of a substance, that is emitted by a source, in a receptor or "target". In order to apply such models it is necessary to classify the main sources of the pollutants, to characterize them, to identify the typical weather conditions in the area and its topography, and to classify the ultimate sinks (areas of pollutant effects on the soil). The concentration C of an air pollutant at coordinates (x,y,z) from a continuous source downwind is given by the equation of diffusion in a steady-state spatial domain (Lamb and Neiburger, 1971):

$$C(x,y,z) = \frac{Qk}{\pi U \sigma_z \sigma_y} e^{-\frac{1}{2}\left(\frac{y^2}{\sigma_{y^2}}\right)} e^{-\frac{1}{2}\left(\frac{z^2}{\sigma_{z^2}}\right)} \quad (1)$$

where C (x,y,z) is the concentration expressed in g/m^3, Q is the pollutant emission rate (g/s), k is the conversion factor (from g/s to g/m^3), U is the average wind speed (m/s), and σ_y ,σ_z are respectively the standard deviations of plume concentration distribution in the horizontal and vertical directions (m). The values of σ_y and σ_z, significantly affect the evaluation of pollutant dispersion, and depend on the stability of the atmospheric conditions. These values are usually estimated on the basis of empirical relationships which link air turbulence with parameters easily obtainable from meteorological stations (i.e. wind speed, solar radiation, cloud cover, standard deviation of wind direction, etc.) (Pasquill, 1961). The case study analysis was performed using BREEZE ISCST3, which integrates equation (1). This model implements and combines several algorithms in a set of two software programs, that are used to assess the impact of air quality emissions in industrial complex. The analysis of the frequency of exposure, however, has been computed with a Visual Basic routine developed (FROD-CODE) in order to define the exposure frequency (98th percentile), and evaluate the concentration levels in exposed receptors identified in the study area.

3. Case study

The case study examines the project of a municipal waste landfill in an area North of Naples, called "Cava del Cane" The study was carried out during the landfill design trying to define the management requirements, with the aim of reducing the odour emission impact on the population. The landfill has a surface area of 12,000 m^2. It is located in an area surrounded by several towns, houses, music halls and sports centres, schools and hospitals (Figure 3). The computational domain is a 16 km^2 square area, centred around the landfill; as illustrated in Figure 3, there are scattered houses in the vicinity of the landfill (approximately 500 m from it), and within a radius of 2,000 m there are the centres of the towns of Marano and Chiaiano, and the main hospitals of the city of Naples. The maximum altitude of the area is 430 m above sea level (a.s.l.) and the minimum is 116 m. The area was divided into regular 100 m x 100 m cells, creating a total of 1,600 cells; a receptor 2 m from ground level was placed in the centre of each cell (giving a total of 1,600 receptors). The land has a very particular topography, and is very dense populated; for these reasons a high-resolution discretization was chosen to accurately represent the domain. Meteorological data measured on an hourly basis for the year 2007 from the nearest monitoring station (AM 289- Capodichino unit), was used. The wind rose, comprising the speed and direction of the wind, is shown in Figure 1. Furthermore, in the study 3 sensitive centres (SC) were identified (Figure 3):

1. SC-1: "Kennedy" sports complex (820 m from the landfill);
2. SC-2: "Istituto suore discepole di Gesù" Marano school (1,300 m from the landfill);
3. SC-3: "Monaldi" hospital (1,500 m from the landfill);

For SC-1, SC-2 and SC-3, a specific time analysis, using the FROD-CODE routine, was computed.

Emission of odorous substances

Odour emissions from a landfill site are due to the anaerobic degradation of putrescible substances in the waste are dependent on many factors, most of which are operational factors. A number of critical issues about the identified receptors has been revealed by a preliminary study based on the application of Italian regulatory rules (Decreto Legislativo n.36, 2003; Directive, 1999/31/CE, 1999). Consequently, suitable additional management requirements have been considered to minimize the emission of odorous substances. In particular: 1) the quick assignment of the waste during the day, the creation of cells of 4 or 5 m in height, and the covering the waste throughout the day with a clay layer of 0.5 m minimum thickness; 2) the placement of a network of extraction wells in the waste layers to maintain the volume of waste under pressure, and the treatment of the intake air with a suitable bio-filter; 3) the scheduled spraying of water containing specific enzymes and/or odorant substances on the waste

surface layers. Consequently, with these requirements, it is possible to categorize the following sources of odorous substances emission, part of the source S (see Figure 2), that are assumed to be:
1. The active cell, (surface area of 300 m^2), characterized by an emission factor equal to 60 o.u./m^2s (S_1 source);
2. The entire surface of the landfill (amounted to 12,450 m^2) characterized by an emission factor equal to 6 o.u./m^2s (S_2 source).
These assumptions concern the whole operating life of the landfill. The combination of the two emissions would be the worst condition and the most cautionary case of the study.

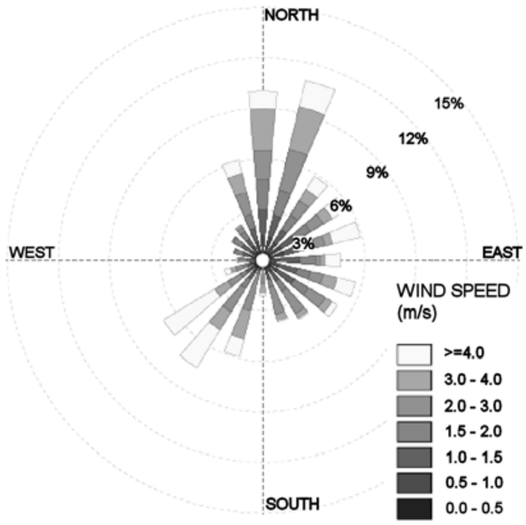

Figure 1: Wind rose for the year 2007.

Figure 2: Sources of landfill S.

4. Results and discussion

Odour concentration was calculated for each receptor on an hourly basis and at the 98th percentile value by using FROD-CODE. The analysis was carried out on a quarterly and annual basis. The results of this analysis are shown in Figure 3, where odour iso-concentration curves (of the 98th percentile) are represented. These highlights the areas where the odour concentration values are equal to 1.5 o.u./m^3 and 3.0 o.u./m^3, which represent more intense smell perception conditions. This figure shows that the area where values exceed the reference value has an irregular shape that extends mainly in the directions of north, south-west, north-east and south-east. The odour contours do not include the towns of Chiaiano and Marano, and the hospital (SC-3), but includes some houses close to the landfill in the north-west direction, the Marano school (SC-2) and the Kennedy sports complex (SC-1). Table 1 shows the results of the time analysis,and reports the number and percentage of times the reference 1.5 o.u./m^3 and the highest threshold of 3.0 o.u./m^3 were exceeded for the three sensitive centres considered (SC-1, SC-2 and SC-3). The data reported in Table 1 show that SC-1, the nearest SC to the landfill, is where the highest threshold (3.0 o.u./m^3) was exceeded the most.

Table 1: Percentage of threshold exceeds in the sensitive centres throughout 2007

SC	Exceeded values 1.5 o.u./m^3		Exceeded values 3.0 o.u./m^3		98th percentile [o.u./m^3]
	n.	%	n.	%	
SC-1.	183	2.09	73	0.83	1.71
SC-2.	200	2.28	41	0.47	1.78
SC-3	76	0.87	0	0	0.70

In SC-3, the farthest SC from the landfill, the situation is more reassuring, with values of the 98th percentile odour concentration being below the perception threshold of 1.0 o.u./m^3. For SC-2, the situation is different: although the 3.0 o.u./m^3 value is less exceeded than in SC-1, the odour concentration at the 98th percentile exceeds the 1.5 o.u./m^3 threshold 200 times.
These results are due to the weather conditions and the topography of the area; SC-2 has a topographic altitude lower than the emission source. The analysis shows that in the most adverse weather conditions there is a stronger perception of odours: the centre of Chiaiano and the hospitals of Naples are outside the odour contours with concentrations exceeding the value of the thresholds indicated, but some houses very close to the landfill, for example the Kennedy sports complex (SC-1) and part of Marano, are affected by more frequent perceptions of more intense odours. Interestingly, with the 1.5 o.u./m^3 threshold at the 98th percentile the absence of perception of odours is not guaranteed, but an odour frequency of only about 2 % is assured.

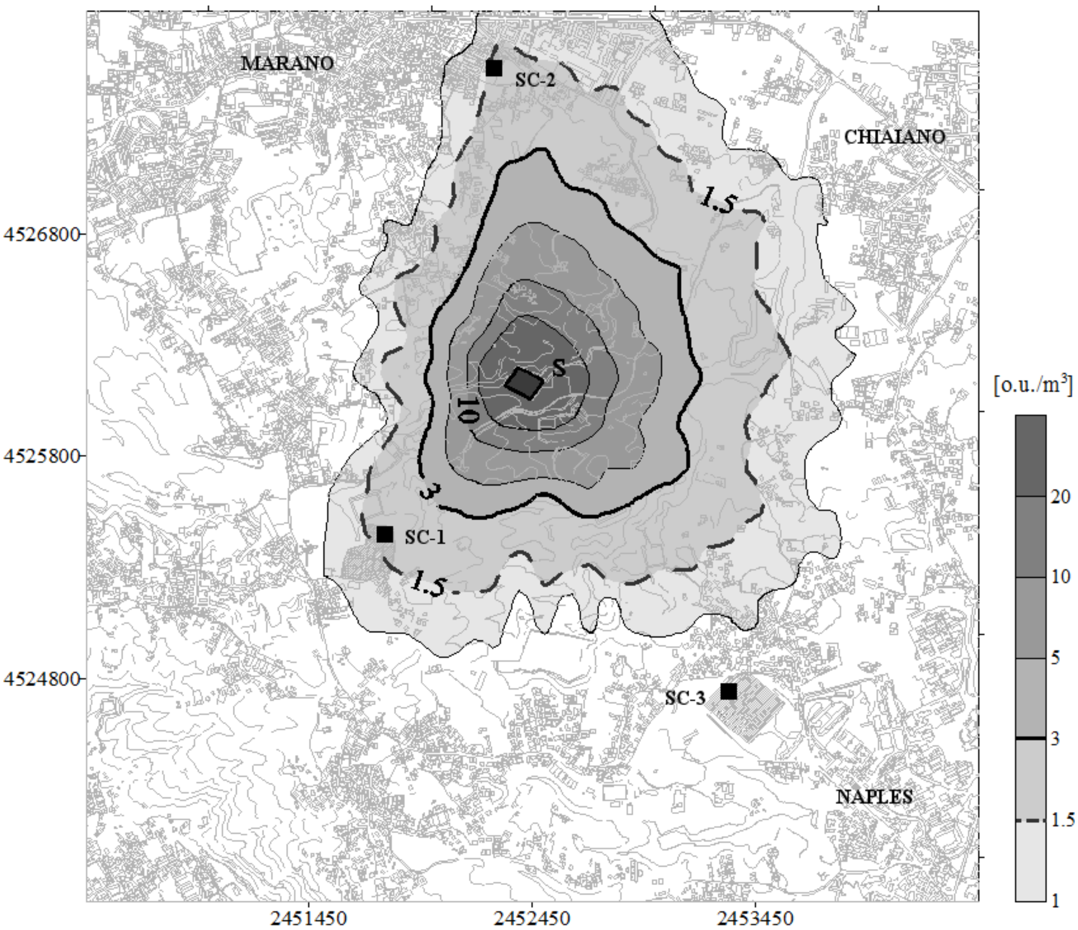

Figure 3: Odour iso-concentration curves (98th percentile) during the simulation time.

5. Conclusions

In this paper, the dispersion of odorous substances emitted from a landfill located in a highly urbanized area has been assessed. In the case study the perception phenomena do not reach the neighbouring densely populated towns and the threshold value is exceeded only at scattered houses close to the landfill. To mitigate odour exposure, landfill management provisions should be more stringent than those required by current regulations. Otherwise, in the most adverse weather conditions, the area may be affected by olfactory nuisance. The obtained results allow to define the extent of the problem by highlighting the main issues. The methodology can help to implement a monitoring system, with “real time” weather information acting directly on biogas collection network and a sprinkler system to cope with the worst case scenario.

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