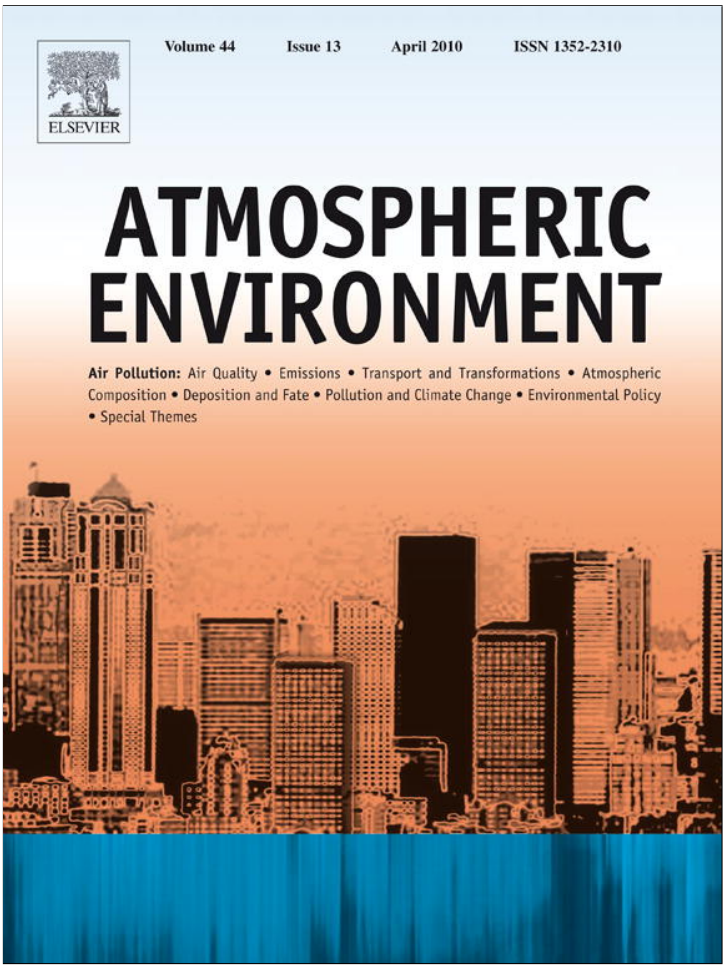

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Identification of odour sources in an industrial park from resident diaries statistics

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ABSTRACT

A methodology based on social participation through the use of resident diaries was applied to evaluate the odour annoyance in the surroundings of an industrial park in Belgium during one year. The studied area covers about 8 km^2 and includes13 potential odour emitting facilities. The network involved 44 residents in the survey, among whom 19 were particularly considered for a detailed analysis. The questionnaire aimed at providing an odour rating twice-daily on a 6-level scale together with an odour type.

The fact that the response rate corresponding to "no-odour" was high (79%) is particularly discussed. Some tests are proposed to check the plausibility of the answers, the coherence within clusters of residents and the individual performance of respondents to discriminate among odour ratings. The odour rose is presented as an attractive and visual tool, particularly suited in the case of multi-source areas, to map the different odour emissions, to point out the most worrying ones, to identify others creating less annoyance and possibly new unpredicted ones. The resident diary method has proven to be particularly useful, conjointly to other ones, to the case of multi-sources facilities in large areas, when the purpose is the assessment of the long-term evolution of odour annoyance.

1. Introduction

Malodours emitted by multi-source facilities, like industrial complexes, have become a major concern for local authorities because the resulting annoyance in the neighbourhood is generally high compared to a single source one. In the case of such multi-source odour emissions especially, common chemical analyses or odour concentration measurement methods are not often applicable. The resulting global annoyance cannot actually be assessed neither by physiological techniques nor by the methods of physical chemistry (VDI, 1993). Socio-economical factors, like the relations between the resident and the different companies, the gender or time spent at the current address influence the odour acceptability (Cavalini et al., 1991; Steinheider and Winneke, 1993; Pierrette and Moch, 2009). It is well known that the absence or presence of background odours may also have a significant effect (Nicell, 2009). Multi-source industrial plants are likely to add to those influences the fact that both the background itself and the emerging odours are complex mixtures of different odour types, which fluctuate with time.

A possible way of assessing the odour annoyance in such cases could be the use of an atmospheric dispersion model. However models calculate the odour exposure, depending on the occurrence frequencies and on the concentration of odours. Odour impact on neighbouring population is a wider concept, involving additional characteristics, like odour hedonic tone and offensiveness or intensity to quantify the odour level. Trying to estimate odour impact from odour exposure requires the availability of dose – response relationships which are sometimes deduced for specific facilities, such as sewage treatment works (Van Broeck and Van Langenhove, 2000; Miedema et al., 2000), but not for complex multi-source plants.

Hence, it is essential to make a global assessment of the odour annoyance, using the residents themselves as measuring tools. Social participation and strong community involvement in detecting odour events may provide an attractive solution to identify odour sources and to assess odour annoyance, while offering significant public relations benefits for the concerned stakeholders (Tapper and Sudbury, 1991). Such a monitoring technique is presented in this paper, applied to a multi-source industrial area and with the aim of demonstrating the concept, particularly relevant for environmental management and regulation. Resident diary results bring a complementary light with respect to more traditional odour assessment methods.

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2. Possible methodologies of population survey

Such an approach, involving social participation, may be applied in three ways:

- collecting and analysing complaints data,
- administering and analysing one-shot surveys concerning local residents,
- questioning resident panellists on repeated occasions or asking them to regularly complete odour diaries.

Collecting data on complaints has several drawbacks (VDI, 1993). Complaints are only made in case of significant odour impact and concern only a small portion of the population. Absence of complaint does not automatically mean that there is no odour, because many people never make complaints. On the contrary, some people make frequent complaints, even for trivial causes.

"Once-only" surveys have the great advantage over complaints statistics in that a representative sample of the population can be selected (VDI, 1993). The main result obtained by such surveys is the cumulative experience of respondents over a long period of time. Different types of surveys can be tested. Van Broeck and Van Langenhove (2000) compared telephone and postal survey methods and preferred the telephone method. The main reasons were the short completion time (about 5 min per respondent), the higher response rates and the simple interpretation of the results.

Whatever the method used, the questionnaire must be based on experience gained by previous studies. Questions must be formulated in such a way that the survey evaluates the situation of the entire group of emitting facilities within one or two years, so that seasonal effects could be taken into account. Different "model" questionnaires are used or adapted to the specific situation (Seffelaar et al., 1992; Radon et al., 2004). For instance, the German VDI guideline (VDI, 1997) proposes 10 questions about pollution and annoyance reaction.

In each case, authors stress the particular importance of the sample choice to warrant that a representative statement concerning the degree of odour annoyance in the affected population can be achieved. Usually, the sample must be selected randomly in the investigated area and must respect the demographic profile of the region, i.e. having the same proportions as the eligible population of age class, gender, category of living area (land use), profession etc. Once-only survey methods supply different results, for example, the global profile of the questioned population by means of factor analyses (Seffelaar et al., 1992), or concentration–annoyance relations for homogeneous industrial or agricultural sectors (Van Broeck and Van Langenhove, 2000; Miedema et al., 2000), or contextual and individual factors linked with the level of odour annoyance for a given population (Pierrette and Moch, 2009; Radon et al., 2004; Steinheider and Winneke, 1993). The disadvantage of single-shot surveys is that such results cannot be broken down to cover individual events. They are the image of the accumulated sensation of annoyance and cannot be used to describe its time variation.

Using the method of resident diaries or regular questioning of a population panel partially corrects those weaknesses. It allows both monitoring odour events on a short-time-basis and assessing the global annoyance profile, by integrating the whole data collection over long periods. Moreover, the resident answers provide information about both the presence and the absence of odour. The method is also much cheaper than systematic expert analyses. Its main disadvantage is the longer period during which people must be involved. So, it is seldom possible to set up a random population sample and to respect the demographic profile of the investigated zone. Resident diaries generally involve volunteers who are recruited in the estimated immission area (Wing et al., 2008; Aitken and Okun, 1992; Gallego et al., 2008). Sometimes, odour panellists are selected for living within or adjacent to a predefined spatial grid, but anyway, they have to accept to be regularly questioned (Guo et al., 2003). In any case, it is always useful to train the panel members before the study, either by odour intensity estimation of a set of butanol dilutions (Nimmermark et al., 2005; Guo et al., 2003) or by asking participants to choose which of different vials has an odour (Wing et al., 2008) or at least by inviting them to attend preliminary community meetings helping to design the data collection (Aitken and Okun, 1992).

The responses of resident panellists may be used to fulfil different objectives.

- The most obvious goal is the public awareness and its better understanding of odour generation and dispersion.
- On a more scientific level, a second goal is the monitoring of odour events and their connection with environmental or weather variables. Data processing may lead to the distribution in space and time of the annoyance. More particularly, it should be possible to demonstrate the differences existing between odour annoyance in the investigation area and in a neutral control area.
- Some model developers are also using resident diary results to calibrate or to validate their models (Nimmermark et al., 2005).
- Outcomes of repeated questioning of resident panellists may also aim at calibrating a dose–response relationship for the definition of odour impact criteria (Gallego et al., 2008).
- Correct processing and reporting of such data by an experienced and acknowledged scientific team represents an important weight in negotiations with the operator of the facility or with public authority. This could result in correcting the production process, or re-designing it, or setting up odour reduction or remediation systems.
- By means of remote control, a sampling pump can be activated by the potentially affected people during episodes when high odour intensity is perceived (Gallego et al., 2008). This way, odours are dynamically sampled for further analysis in the laboratory and the results may be used to identify the origin of the annoyance, which is particularly useful in situations involving unpredictable odour occurrences.

The present paper discusses the applicability, advantages, disadvantages and limitations of the resident diary method in the case of an industrial park in Belgium. For this particular case study, it discusses also the possible uses of the method and stresses the possibility of mapping odour sources by odour roses.

3. Materials and methods

The case study concerns an industrial park in Belgium. Prevailing wind directions are North-East and chiefly South-West. The industrial zone is situated in an urban area, with a population density of about 1300 inhabitants per km^2 for the whole city (48% male and 52% female). The population by age is: under 20 years, 24%, 20–65, 58% and over 65 years, 18%. Fig. 1 shows the studied industrial area with main roads and the 13 companies involved in the global odour annoyance.

All 13 companies are potentially odour emitters. Table 1 indicates their activity. As seen on the figure, the industrial park can be separated into two main parts: the West part, with companies A–E, and the East part, including companies F–M.

The network of volunteer residents was instigated in September 2007 on the initiative of Ecovie, a local environment association. Beginning with a handful of persons, the network included at the

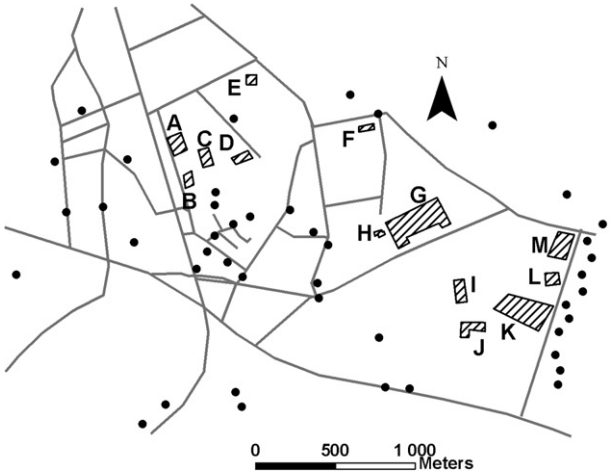

Fig. 1. Location of observers (black dots) and companies (cross-hatched polygons) in the industrial park area.

end of 2008 a total of 44 residents identified by black dots on Fig. 1. The investigated area covers about 8 km^2 and the maximum distance between two panel members is 3.7 km.

The involvement of the university research group and of Odometric as partners of the odour monitoring study dates from March 2008.

Except for two persons, no particular training was organised, however two meetings were planned with the panel members in order to present the first results and to redefine the frame and the instructions of the procedure. Moreover, a preliminary survey was conducted through the panel members to better describe their general profile. For this study, the proposed series of questions was adapted from VDI 3883 Part 1 guideline (VDI, 1997).

As far as the monitoring by resident diaries is concerned, the questionnaire evolved with time and the final version prescribed the following requirements to the panel members:

- if possible, daily observations, two times a day,
- two set periods: 7–9 am and 6–8 pm, but any particular observation outside those ranges can be mentioned,
- sniffing near their home, but outside,
- estimation of the odour rating on a 6-level scale (0 = no odour, 1 = scarcely perceptible, 2 = weak, 3 = sharp, 4 = strong, 5 = very strong, 6 = unbearable),
- selection of a unique odour descriptor among a list of 14 terms,

The collection of record sheets forms a diary which must be transmitted on a weekly basis. Data are encoded by the local secretary of Ecovie, validated and formatted by Inter-Environnement Wallonie and processed by the University of Liège and Odometric.

Table 1
List of the 13 companies located in the industrial park.

Label	Activity
A	Slaughterhouse
B	Sausage manufacture
C	Animal by-products rendering
D	Cosmetics and pharmaceutical products
E	Construction waste recycling
F	Potato-based products
G	Chemical products
H	Glue and latex-based products
I	Potato crisps
J	Poultry slaughterhouse and frozen products
K	Urban wastewater treatment plant
L	Frozen vegetables
M	Linseed oil-based products

The final version of the questionnaire is the result of some discussions between the three partners. Although it is inspired by some existing guidelines, it does not correspond to any standard survey form, but is specifically tailored to match the local requirements. All panel members had been informed that the odour rating scale refers to an annoyance level rather than only an odour intensity. For the purpose of the present study, the twice-daily odour rating data were sometimes considered as distributed on a linear scale between 0 and 6 and therefore, likely to vary with time over that continuous scale. This particular point is discussed further on.

The initial survey form proposed a list of 27 possible terms to qualify the odour. This list was reduced to 14 items by regrouping similar odour types.

Enrolled residents took part in the survey for one year, from September 2007 to the end of August 2008. A total of 22 646 individual observations were recorded.

Wind speed, wind direction, temperature, atmospheric pressure and solar radiation are recorded hourly by a local weather station.

The paper also briefly discusses some results deduced from other studies, for which resident diary method was also applied, i.e. a landfill site near Brussels, another landfill site during the rehabilitation phase and a goat breeding facility.

Data were encoded in Excel and processed through Visual Basic Macros and Statistica package. Spatial data are analysed by Arc Map Geographical Information System.

4. Results

Personal data collected through the preliminary survey show that gender distribution of panel members is close to the numbers for the real population (51% male-49% female), their age ranges mostly from 41 to 60 (45%) and from 61 to 70 (32%). Only 16% are in the range 20–40 and nobody is under 20. That is a usual bias for this kind of systematic repeated survey: available persons who accept to voluntary sniff the air twice a day during long periods are rarely young people. In this case, 65% have no job outside their home and nearly all panellists claim to be available at home during the suggested sniffing times of the day. Fig. 2 shows the histogram of the distances measured on a map between each neighbour panellist and the closest company in the industrial park. The distances are in the range 65–1940 m of which more than 50% are under 500 m. Residents have been living there for 3–66 years and nobody has just arrived in the neighbourhood.

Among the 22 646 individual observations for the full data set, 6336 concerned year 2007, which may be considered as a launching period for the survey. Only 25 residents were initially involved, they used their own vocabulary to describe the odour and noted their odour observation at any time of the day and, as a result, cross analysis between residents was impossible. Moreover, no reliable meteorological data were available.

This first test period led to the adaptation of the questionnaire to match the requirements of statistical investigations. The following analysis concerns year 2008 with 16 310 individual observations.

Even for that final version, the completion rate was highly variable from person to person: from 1 to 1783 answers per resident. A first pre-processing step consisted of deleting inconsistent data and infrequent participation. Except for 2 residents living in a poorly represented zone, those panel members who responded with less than 33% frequency (less than 33% of all possible twice-daily period entries) were eliminated from the data base for the purpose of statistical comparisons. For the remaining selected

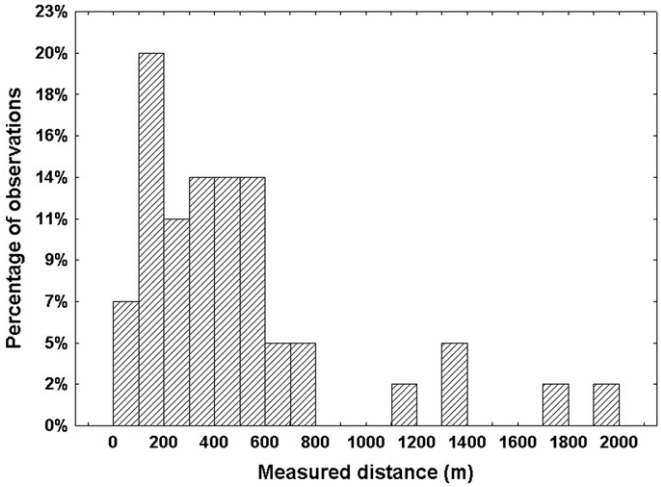

Fig. 2. Histogram of measured distances from panel members to the closest odour source.

panel members, responses were considered to be sufficiently reliable to avoid any weighting when averaging the odour ratings. The final table considered only 19 residents and 11 713 valid reported observations, among which 6409 were for common imposed periods ("morning" for 7–9am and "evening" for 6–8 pm). However, all involved residents were kept for other analyses, such as odour type statistics or odour roses.

A first essential result deduced from the odour ratings data file is that 79% of the observations correspond to "no-odour" (0 on the odour rating scale). This means that, overall, a majority of time periods are odour-free in the neighbourhood. From a statistical point of view, this means that the distribution of odour rating values is largely left-skewed, forbidding considering time-average values as reliable statistical characteristics for a given period. For odour ratings above 0, distribution is close to normal and allows the application of statistics. To test the performances of respondents to discriminate among odour ratings in that upper part of the scale, we calculated a coefficient of discernment (CD), as suggested by Aitken and Okun (1992), and defined, for each respondent, as:

$$\mathrm{CD} = 1 - (\sigma_{1-6}/\sigma_{\max}) \tag{1}$$

where, σ_{1-6} is standard deviation of the number of responses for each of the 6 ratings, from 1 to 6, $\sigma_{\max}$ is the maximum standard deviation for the number of responses above 0 for this specific respondent (standard deviation is maximum if the respondent circled always the same odour rating above 0).

The CD may vary from 0 (poor discernment, only one of the 6 ratings used by the respondent) to 1 (the respondent uses the full scale range).

In our case, for the 19 considered residents, CD varies from 0.33 to 0.79 with a mean value of 0.55. These results indicate, for most people, rather good discrimination performances for the odour rating. This was not the case for all residents at the beginning of the survey. Some people, feeling particularly annoyed by the odour, always circled 5 or 6 on the rating scale. After having been explained that their data were unusable to assess the odour emission variability and to point out the main pollution sources in the industrial park, they corrected their behaviour and used the full odour rating scale range.

For such a large area under investigation and especially because local residents are influenced by different odour sources, quite homogeneous clusters of panel members have to be formed. It is well known that the number of clusters and the number of respondents in each cluster largely determine the statistical results (Van Broeck and Van Langenhove, 2000). Moreover, in order to isolate the specific impact of odour emissions from other possible effects on the neighbourhood, at least one cluster must be situated outside the influence area and should be used as a reference cluster.

The reliability of the odour rating statistical results within a cluster depends on the number of residents in a cluster. For example, confidence intervals around a mean value are proportional to 1 over the square root of n, where n is the sample size.

Unsupervised clustering, such as correspondence analysis, just based on the existing data, led to incoherent group formation for the case under investigation. The similarity of answers given for odour rating or even odour type is not a reliable criterion for clustering, especially when considering so few observers. So, the single criterion used to form spatial clusters was eventually the simple geographical location. Fig. 3 shows the six identified clusters on the map. They were delineated with the aim of representing 6 different zones with respect to azimuth directions and to the closeness of odour sources. Table 2 gives their characteristics. The observation completion rate is calculated as the percentage of valid observations with respect to all possible data entries.

Unfortunately, despite the successful enrolment of residents for this survey, it is difficult to form clusters including more than 4 or 5 reliable respondents. It is especially true for the South-West zone, located at more than 1350 m away from any odour source and which could have been considered as reference zone, but the 4 residents had to be eliminated due to infrequent responses. More generally speaking, this is an important drawback of the resident diary method. Even in ideal cases, it is really difficult to keep the resident motivation for long observation periods when practically no odour is recorded in the reference control zones. In this particular case study, that was not such a big problem since any upwind cluster could be considered as a control zone with respect to other ones. Moreover, the rare responses from the 'control group' were always 'no odour'.

As shown on the wind rose of Fig. 4, the survey period was characterized by winds from South-West and North-East, corresponding to the prevailing wind directions for the area. In order to appreciate the time evolution of odour rating, we calculated an Odour Annoyance Index (OAI) defined as (VDI, 1993):

$$\mathrm{OAI} = \frac{1}{N_t}\sum_{i=0}^{6} w_i N_i \tag{2}$$

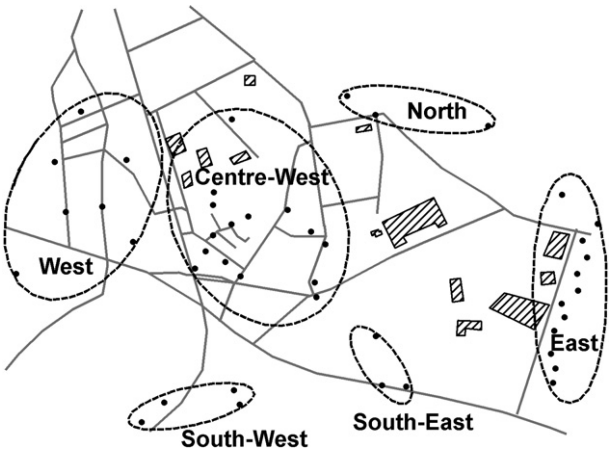

Fig. 3. Six clusters of residents with comparable estimated odour exposure in the industrial park.

Table 2
Characteristics of the 6 identified respondent clusters, with the completion rate of the selected respondents for each cluster.

Name	Location	Number of total respondents	Number of selected respondents	Observation completion rate
West	At the West of the whole industrial park	7	4	74%
Centre-West	Between the two parts of the park and more close to the West part	15	5	73%
North	North of the whole park	3	3	92%
South-West	At the South of the whole park and rather far from it	4	0	0%
South-East	Between the two parts of the park and more close to the east part	3	3	45%
East	At the East the whole industrial park	12	4	60%

Where, N_t is the total number of observations for the investigated zone or period, N_i are the number of observations corresponding to the odour rating i ($i = 0$–6) for the same zone or period, w_i are corresponding weighting factors (in our case, $w_i = i \times 16.67$).

The global time evolution of twice-daily OAI's averaged for the whole park or by zone does not provide any relevant information. No clear trend, no seasonality and no big differences between zones are observed, except for an OAI level slightly larger in zone "Centre-West" with respect to the others. It is already an interesting outcome in itself, which confirms that, in the neighbourhood of such industrial parks, the odour perception is rather constant over the whole year. Production peaks or activity reduction as well as downtimes or periods of annual leave are indeed rarely synchronized among the different companies. The larger value for "Centre-West" zone may be attributed to its central situation among the various odour sources.

Intra-week variation is more noteworthy (Fig. 5). A clear decrease of odour rating is always observed during the week-end period together with an odour peak in the middle of the week. However, it is difficult to be sure that the intra-week odour variation is not a bias due to the presence or the absence of residents at home.

Still on a shorter time-scale, Table 3 gives the statistics of odour observations for the four periods of a "typical" day, averaged for two respondents from zone "Centre-West" and zone "East". Here, the perception rate is calculated as the percentage of odour rating above 0 with respect to the total number of observations. Those results are just supplied to illustrate the potential of the method for two particularly regular residents, but they should be confirmed by further investigation. In this case, the Odour Annoyance Index reflects exactly the perception rate, i.e. the number of odour episodes is higher during the day and the night, but, when an odour is perceived, its average rating is nearly always the same, whatever the period of the day. A slight increase of the perceived odour level is observed during the night, which may be due to a more negative odour appraisal during rest periods.

Using the information relative to the odour type could be a possible way of validating the data. Fig. 6 shows the usage rate of two odour types, "potato, fried food" and "animal carcasses" distributed among the different days of the week (Fig. 6a) and among the different resident zones (Fig. 6b). The first type should concern essentially companies F and I, located in the East part of the park, and the second one should be typical of companies A and C, in the West part. Logically, the "animal carcasses" odour is most smelled in the Centre-West zone and the "potato" odour is most often detected in the East zone, but also present in the Centre-West and in the North zones, which are not so far from company F. Regarding time evolution during the week, the "potato" odour is highly reduced during the week-end, corresponding to the reduced activity of the companies, while the odour of "animal carcasses" is more constant. Those trends confirm intuition, as the storage of animal carcasses during the week-end continues to be an odour source, even if activity is reduced.

But the odour type information is not only a way of validating the responses. Another interesting result issued from the odour types is the intensive use of the type "fuel, gas" for the western-most resident. This person is actually more annoyed by the traffic and by a close filling station than by the industrial park itself. Globally, the information about odour type allows highlighting the most worrying sources, potato-based products and crisps, cosmetics and linseed oil in the present case, as well as the ones which create less annoyance, such as the poultry slaughterhouse or the wastewater treatment plant.

Clearly, the cross analysis of both odour rating and odour type could be used to validate the data and to question about their reliability. Nevertheless, the resident responses still remain subjective impressions. Even the mention of a given odour type is not always objective. If a resident feels particularly annoyed by the company close to his home, he probably will circle more frequently

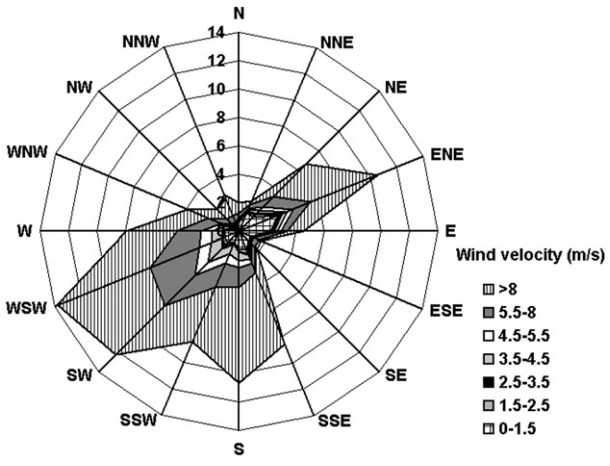

Fig. 4. Global wind rose for the whole investigation period on the basis of hourly observations (radial scale is in % of occurrence for each sector).

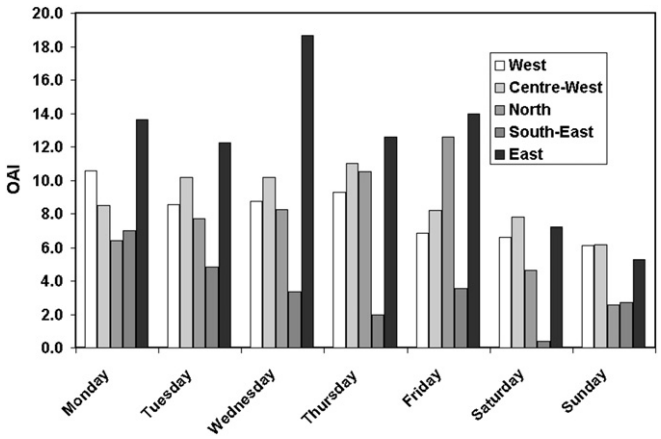

Fig. 5. Intra-week variation of Odour Annoyance Index for the 5 considered zones.

Table 3
Odour observation statistics for 4 periods of the day averaged for two residents.

Period of the day	Number of available observations	Perception rate	Average Odour Annoyance Index	Average Odour rating above zero
Morning (7–9 am)	1368	12%	7	3.3
Day (9 am–5 pm)	543	57%	30	3.3
Evening (5–8 pm)	1253	15%	7	3.2
Night (8 pm–7 am)	128	50%	23	3.8

the odour type corresponding to the odour emitted by the company.

Of course, despite its subjective character, perceived annoyance is relevant as a study parameter, but not if wrong information is supplied with the only aim of accusing a company. It is thus essential to cross the resident responses with a tangible external measured variable. The obvious choice is the wind direction, which can be used for plausibility checks, to detect eventual observations with incorrect spatial or time attributes. Table 4 presents the responses of a resident from Centre-West zone regarding the odour of "potato, fried food" with respect to the sectors of wind origin and to odour rating values. Above all he is logically influenced by the odour of companies F and I when the wind blows from East or North-East. However, the responses corresponding to wind sectors W, SW or NW, sometimes with high odour rating values (4 or 5) are questionable, even if some of them can be explained by local flow pattern in calm wind speed conditions.

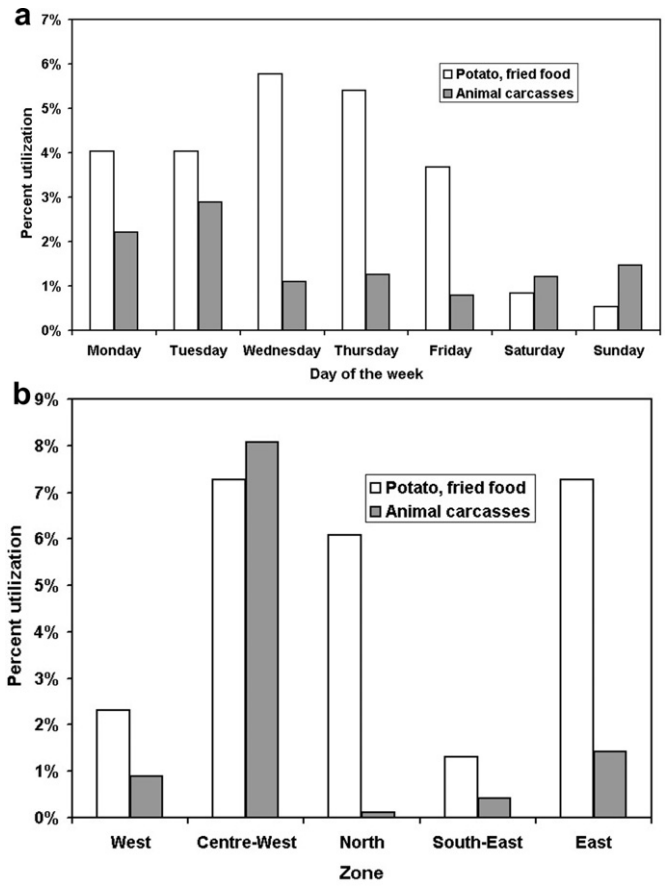

Fig. 6. Distribution of the utilization rate of two odour types among the days of the week (a) and among the observation zones (b).

Table 4
Repartition of the number of responses concerning the odour of potato for a resident of Centre-West zone for the 8 wind origin sectors and the 6 odour ratings.

Wind sector	Odour rating						Total sector
	1	2	3	4	5	6	
N	0	0	3	4	0	0	7
NE	3	3	49	31	31	0	117
E	0	24	33	23	8	0	88
SE	0	2	1	0	0	0	3
S	0	0	0	0	0	0	0
SW	0	0	1	0	0	0	1
W	0	0	0	0	2	0	2
NW	0	0	1	1	0	0	2
Total rating	3	29	88	59	41	0	220

Odour roses offer a very attractive and visual approach to combine odour rating observations and wind data in a global presentation. Gallego et al. (2008) suggested episode roses showing the frequencies of the different wind directions when an odour episode occurs. Here, the odour rose is presented in the same way as the usual wind rose, but by plotting the OAI in place of wind velocity occurrences on the radii of the circular diagram for each wind sector. It consists of selective average of OAI for all sectors of the wind rose. Therefore, the final diagram shows, in polar coordinates, the distribution of OAI for 16 wind directions experienced at a given location and for a given period of time. As wind direction is recorded in terms of its origin, the rose should normally point at the odour emission. Fig. 7 shows 5 odour roses calculated for the average OAI of each of the 5 defined zones and for the whole investigation period. This diagram is reassuring: each of the 5 odour roses points towards the main odour emission sources of the industrial area and does not reveal any new unexpected source. The absence of illogical odour roses should confirm the reliability of the resident observations.

This is a first step of the analysis, but some less obvious outcomes can be obtained by a more detailed analysis, e.g. by breaking down the global odour annoyance index into the contributions of various odour types. Fig. 8 shows the odour rose corresponding to odour type "fuel, gas" in zone West (mainly for the western-most resident) and two average odour roses corresponding to zones Centre-West and North for odour type "potato, fried food". The first one confirms that the odour of fuel or exhaust gas comes from diverse diffuse sources, mainly the road traffic. The two other ones could be used to identify the most annoying source of potato and fried food odour. Two companies, F and I, are indeed potential emitters of such odour. The roses plotted on the map could suggest that residents are more annoyed by company F than by company I, but that result must be confirmed by further analyses.

5. Discussion

The resident diary method has proven convenient and cheap for long-term follow-up of complex odour emission areas, especially when spatial information is needed. For this particular case study, more than 10 000 reliable odour observations are actually provided over a 1-year period and for many locations inside an 8 km^2 area, and the total cost of the study only includes data encoding and processing. However, any odour monitoring method implying social participation unavoidably leads to important biases. It is particularly true when the involved resident network is closely embedded into a multi-source industrial park; it is difficult to insure an impartial judgement and to avoid some bias in the responses. If doubt arises about the reliability of the observed odour ratings, it is advisable to test or even to regularly train the

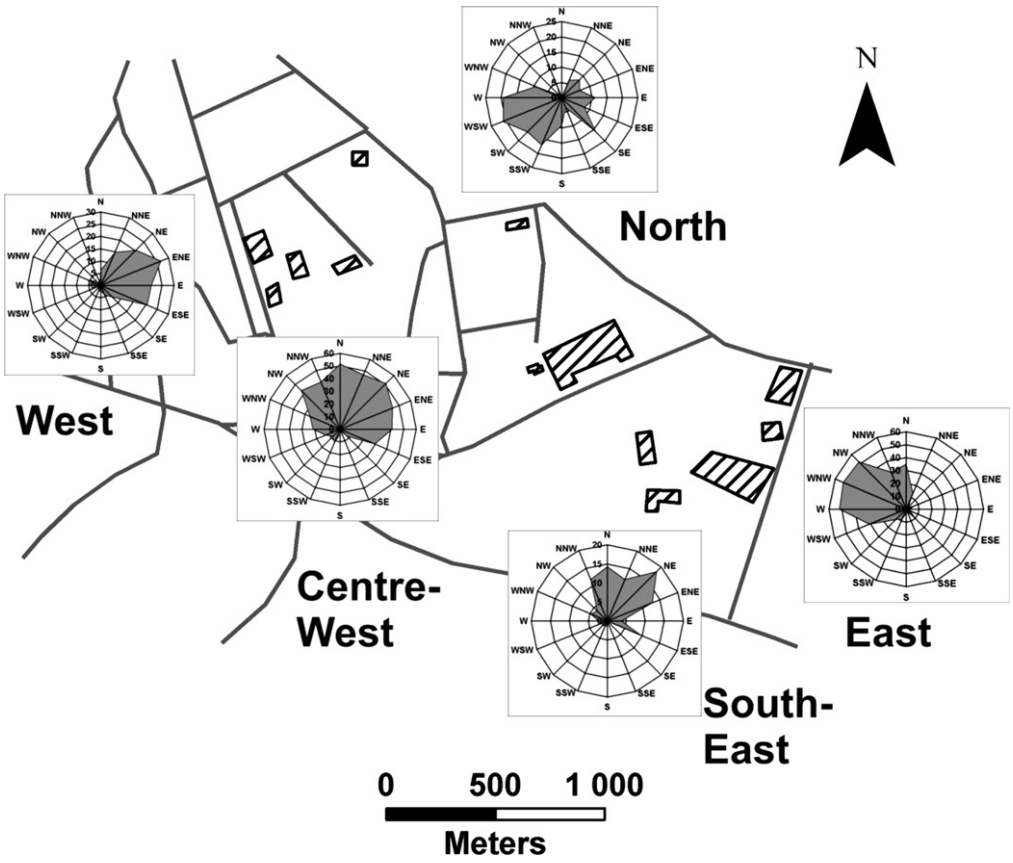

Fig. 7. Average odour roses for the residents of the 5 zones in the neighbourhood of the industrial park (Table 2 indicates the number of observers and the completion rate of responses for each of the 5 zones).

panellists. VDI 3883 guideline (VDI, 1993) suggests to submit various odour samples to the participants and to compare their ratings. The guideline only presents this as a possible method to be used in case of doubt, because "this check is expensive and complex and, to date, such tests do not show any basic difference in the ratings". In our case, just two persons were checked on only one occasion to a butanol reference and the majority of involved residents are inexperienced people. In fact, a rigorous approach should

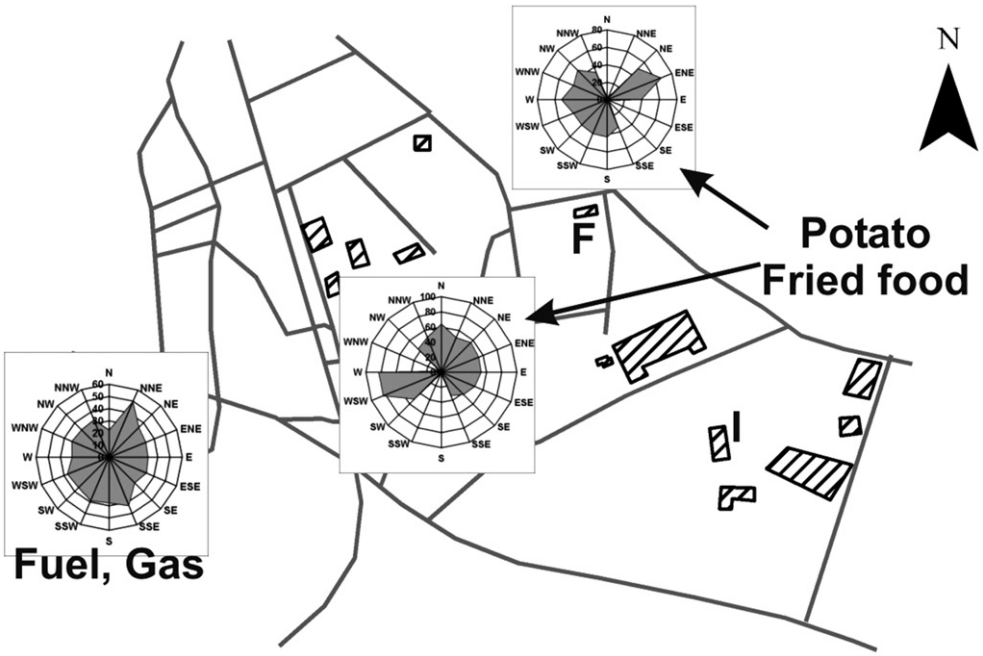

Fig. 8. Odour roses corresponding to different zones for two odour types, "fuel, gas" and "potato, fried food".

be applied at the time of selecting panel members who should comply with different criteria concerning both power of discrimination and odour rating assessment and who should be checked at regular intervals (typically 6 months). Such requirement is demanding and nearly impossible to apply for long-term survey with unpaid volunteers. The present study shows that periodical meetings with the panel together with cross validation against more neutral parameters may be sufficient as long as only global trends are expected. If necessary, the survey should be completed with dispersion modelling results based on odour emission rate measurements.

An additional bias could arise from the absence of residents during holiday time or during the week-end or from the fact that people are sleeping during the night and that they do not realize that the area is experiencing a bad odour episode. It is thus essential to make a clear distinction between the absence of response and the recording of an odour-free event.

The absence of people and also the lack of motivation of several residents is the reason for the poor response rate for some panel members for some periods. That could bias the results when calculating odour rating averages which could be influenced by a few high ratings coming from infrequent respondents. Hence, different solutions must be considered to correct the bias. Here, excluding all panel members with a response frequency of less than 33% is a first step towards reducing the bias due to infrequent respondents. Of course, that proportion must be optimised on a case-by-case basis. A second step is calculating OAI values on larger time periods than twice a day. So, the influence of individual responses is attenuated. Fig. 9 shows (white bars) the OAI values calculated on a monthly basis. Now, a seasonal variation is clearly observed, whereas the continuous OAI evolution did not reveal any trend. Finally, average odour ratings could be calculated by weighting the ratings according to the response frequency of residents (Aitken and Okun, 1992). In our case, this additional procedure does not provide any new information (grey bars on Fig. 9).

The judicious choice of data processing methods could be a way of correcting skews in the odour rating distributions and also a way of assessing the reliability of annoyance values. When “no-odour” observations are not too frequent, the median of odour ratings may be calculated in place of the average value. This was successfully applied for a survey around a goat breeding facility, but, in the present case, as “zero” ratings occur for more than 50% of the observations, the median should always be 0. The calculation of the Odour Annoyance Index could be another way of getting round statistical constraints. A more rigorous method should consider separately the odour-free observations and the odour ratings above zero. The former allows deduction of the non-perception rate (or the complementary notion of perception rate) while an average odour level may be calculated for odour ratings above zero, i.e. when an odour is perceived.

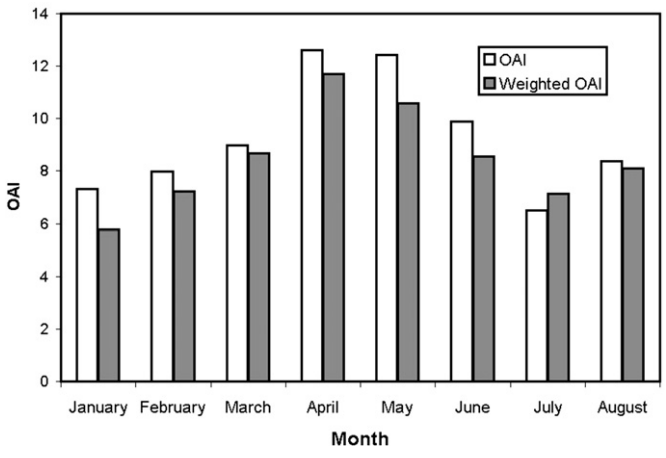

Fig. 9. Odour Annoyance Index averaged on a monthly basis with (grey) or without (white) weighting factor.

Finally, if the results of the survey are used to bring scientific weight to negotiations with companies and local authorities, or to validate the effect of an odour abatement system, it is advisable to keep the odour rating range as small as possible within a cluster and to evaluate reliability intervals taking into account the relative number of respondents within each cluster, as suggested by Van Broeck and Van Langenhove (2000). Consistency of odour ratings among neighbours may be checked using standard deviation. In our case, in the absence of any information about real unbiased annoyance, global uncertainty assessment is actually only based on data dispersion. Except in a few cases, odour roses confirm that residents rarely provide wrong responses concerning the presence or the absence of an odour. Hence, limiting the analysis on odour ratings above 0, the intra-cluster standard deviation has a mean value of 0.52 and a maximum value of 2.06 on the 1–6 rating scale. In terms of confidence interval around the mean rating value within a cluster, the margin could roughly be estimated at ± 1.

Anyhow, when using resident assessment in odour surveys, one must be aware of possible bias and lack of accuracy of the responses and any cross validation procedure is always advisable. The plausibility of the responses should be checked against wind direction and wind velocity, using odour rose plots and the main results of the survey should be compared to those of various complementary methods. Van Broeck and Van Langenhove (2000) compared the responses of a telephone survey to the odour concentration determined using sniffing measurement in combination with short-term and long-term dispersion model calculations. We tested the resident diary method in the neighbourhood of a landfill area near Brussels (Nicolas et al., 2006). One observer in particular, living around 500 m away from the tipping area, regularly noted his perception. During one year, he smelled the odour of fresh garbage 18% of the time. According to our estimations, using long-term dispersion modelling over a period of one year, the percentile running through his house is percentile 85 for 1 ou m^{-3}, corresponding to a waste odour perceived during 15% of the time. The closeness of both percentages could be a first indication of the ability of the method to validate percentile calculation.

6. Conclusion

Using neighbourhood panellists brings valuable information for odour annoyance assessment, because they stay in the designated area and are exposed to the odour frequently. The present study demonstrates the usefulness of the method to map different odour sources around an industrial park. An additional finding could be highlighting new unpredicted odour sources, such as “fuel and gas” in the present case or a wastewater drainage pipe in a study conducted by Gallego et al. (2008). By using tailored questionnaire, the resident diary method could also be applied on a shorter-term basis to the follow-up of odour emissions resulting from any modification of the facility, as in the case of the rehabilitation phase of a landfill area.

However, this evaluation method also presents different drawbacks, as the distribution skew due to the number of times panel members report “no-odour”, the lack of impartiality of some residents or the poor motivation for people living outside the exposed area, which generally results in rejection of the results corresponding to the reference control zone. So, the responses of the panellists should be checked for plausibility and validated against other methods.

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