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Research article

A case study of odour nuisance evaluation in the context of integrated urban planning

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A R T I C L E I N F O

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A B S T R A C T

Odour nuisance poses a serious problem in many urban areas, yet its evaluation and mitigation is often omitted in the urban planning process. By identifying its range and spatio-temporal variations, it could be taken into consideration by planners in urban development strategies and land use decisions. The aim of the study was to present the application of odour evaluation techniques in the improvement of the quality of life in the built environment. The problem of odours is discussed in regard to human health, social aspects and current practices in the management of spatial development. The application possibilities of field olfactometry are demonstrated based on a case study of a municipal landfill which is a major source of odour nuisance for the adjacent areas. The results of odour nuisance measurements were field olfactometry combined with topographical and meteorological data. Using dispersion modelling (non-steady-state Lagrangian Gaussian puff model CALPUFF with dedicated meteorological pre-processor CALMET) it was possible to calculate odour concentrations and to place the measured odour concentrations in a specific spatial context. The obtained results were juxtaposed with local development strategies and discussed in the context of environmental-based planning. We suggest that odour evaluation and dispersion modelling are valid tools in managing the dynamics of urban growth.

1. Introduction

Achieving the best quality of life in urban areas is an increasingly discussed topic among academics, urban planners and policy-makers. The exploration of complex interactions between human activities and biophysical processes is considered challenging and due to the lack of understanding in this field, in the past years there have been numerous investments and land use decisions with a negative long-term impact (Alberti and Waddell, 2000). Therefore, the development of urban areas requires an interdisciplinary approach with contributions from many fields of research. However, the knowledge provided by environmental sciences is fragmentary as particular components of urban ecosystems are isolated (Brand and Thomas, 2005). A sectoral and disciplinary approach for changing urban policies and practices towards sustainability is insufficient so there is a need to integrate many areas of research into holistic, comprehensive systems encompassing all aspects of urban development (McCormick et al., 2013).

In order to solve this problem, environmental issues are underlined in new approaches in urban planning, e.g. urban environmentalism (Brand and Thomas, 2005), the integration of environmental and urban planning or integrated planning (Runhaar et al., 2009; Yigitcanlar and Teriman, 2015), and in many planning and environmental evaluation procedures such as the Strategic Environmental Assessment (He et al., 2011; Lamorgese and Geneletti, 2013; Rojas et al., 2013). However, environmental quality evaluation is difficult to implement in the process of urban planning given the often non-spatial character of obtained results. It is also important to note that the practice of planning supported by scientific methods should remain a flexible process in which social consensus is combined with achieving environmental ambitions and standards (Runhaar et al., 2009). A relaxed approach

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may be an alternative to fixed environmental quality regulations in the process of participatory planning which requires taking into account the local community context (Glasbergen, 2005).

Malodours are an environmental and planning problem but also an important factor in the perception of built environment underlined in the concept of smellscape which refers to the olfactory landscape of the city (Porteous, 1985). Combined with other sensory information, the perception of smell considerably impacts the experience of urban life and should be incorporated into the practice of urban design (Henshaw, 2014). Odour nuisance is a problem in urban areas, for instance in the case of re-development of post-industrial sites or encroachment of housing on industrial areas and sources of odour emission such as landfills or wastewater treatment plants (Lewkowska et al., 2016). Odours are also recognised as a social issue and a source of many complaints regarding air quality (Aatamila et al., 2011; Bokowa, 2010; De Feo et al., 2013; Lewkowska et al., 2015). In order to manage its impact on the urban environment, it is necessary to be able to evaluate emission of malodours reliably and to determine its range and long-term effects. Despite advances in evaluation techniques (Brattoli et al., 2011; Sironi et al., 2010) and research into the strategies for the reduction of odour dispersion (Estrada et al., 2012; Tyndall and Colletti, 2007), it often remains an unsolved issue.

Odour monitoring should be an important element in the evaluation of environmental quality in numerous current urban development strategies, for example in the widely advocated compact city policy or in the case of introduction of housing into industrial estates and the promotion of mixed-use development (e.g. Korthals Altes and Tambach, 2008; Stead and Hoppenbrouwer, 2004). According to experts at World Health Organisation, odour nuisance significantly decreases the quality of life (WHO - World Health Organization, 2000). Although not clearly associated with any specific disease, it may be a source of many negative health effects. Among the symptoms caused by exposure to malodours are headaches, nausea, reflex nausea, fatigue, eye and throat irritation, shortness of breath, runny nose, sleep disturbance, inability to concentrate, and classical stress response (McGinley and McGinley, 1999). It is becoming a widespread opinion that odours should be included among environmental contaminants and subject to regulation (Nicell, 2009).

The occurrence of odour nuisance is difficult to determine directly, and so it is necessary to introduce objectivity into odour impact evaluation (Nicell, 2009). There are several methods used to characterise environmental odours (Bokowa, 2012; Capelli et al., 2011a, 2008). Instrumental techniques such as devices equipped with chemical sensors are commonly used for that purpose but often prove insufficient when dealing with complex odours as their chemical composition does not directly relate to the perception of odours by humans. For this reason, sensory techniques in which the human nose is used as a detector are becoming increasingly widespread. One of the most common of them is dynamic olfactometry in which ambient air is mixed with filtered, odourless air in gradually decreasing ratios in order to determine the odour threshold (Capelli et al., 2011a).

Pollutant concentration modelling is commonly used for evaluation of aero-sanitary conditions, including odour nuisance. It can be used to prepare year's analysis of the concentration of odorants in a given area or to estimate the range of threshold levels excess instances. However, in order to obtain meaningful and reliable results, it is necessary to use an adequate model and to estimate the emissions properly. The dispersion of odours is mostly determined by meteorological and geographical conditions (Hong et al., 2011). Odour nuisance appears episodically, and fluctuations in temperature, wind speed, relative humidity and/or atmospheric pressure can significantly impact the perception of malodour. For that reason, it is important to be able to include spatially and temporally variable meteorological data, as well as topography and land use in pollution dispersion modelling (Carvalho et al., 2006).

The aim of the present work is to demonstrate how the results of the evaluation of odour nuisance coupled with odour dispersion modelling can be applied to the development of local urban planning strategies. In the proposed approach, the assessment of odours by means of field olfactometry and gas distribution modelling is translated into a specific urban context to discuss strategies necessary for odour control and for solving environmental issues in the process of participatory planning. The results of odour nuisance assessment can facilitate the improvement of the quality of urban environment when integrated into land use and planning decisions. This was previously investigated and discussed in the context of urban areas (Capelli et al., 2011b; Invernizzi et al., 2017), particularly in regard to the development of various methods for measurement and evaluation. In this work, the focus is placed on the implementation of the results of such investigations in the urban planning process.

2. Materials and methods

2.1. Measurement of odour concentration using field olfactometry

Odour concentration was expressed in odour units per cubic meter (ou m^{-3}). Odour unit is defined as the concentration of one or more odorous substances that is equal to the group odour threshold, with 123 μg of n-butanol used as a reference. In the European standard (EN13725, 2003) it is recommended to use dynamic olfactometry for assessment of odour nuisance which is then expressed in European odour units (ou_E m^{-3}). However, using this method it is difficult to determine relatively low odour concentrations (less than 25 ou_E m^{-3}). For that reason, field olfactometry, a technique that is intended for odour nuisance assessment when odour concentrations are in the range of app. 1–25 ou_E m^{-3} (Both et al., 2004; Byliński et al., 2017; Lewkowska et al., 2015; Smeets et al., 2007) was used instead. A field olfactometer is depicted in Fig. 1.

Odour nuisance measurements were conducted in the vicinity of a municipal landfill located in Gdańsk, Poland. The landfill is classified as category 3 according to the European reference regulation (1999/31/EC, 1999) and is equipped with systems for biogas recovery and treatment of gaseous effluents. The municipal waste management system is comprised of a sorting facility, composting plant, degassing unit, bioelectric plant and pre-treatment plant. Compost maturation takes place in the open and is the main source of odour nuisance (discomfort caused by exposure to malodorous volatile chemical compounds) for local residents. The composting facility is comprised of 14 composting tunnels. Both the sorting and

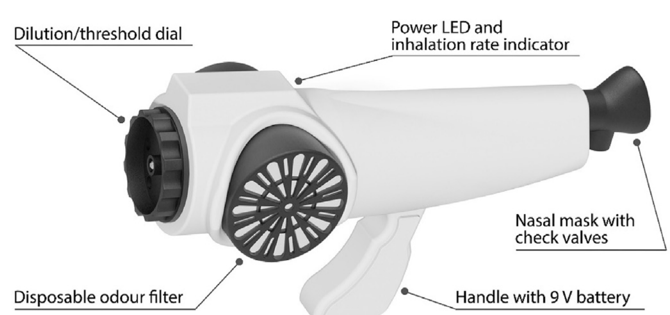

Fig. 1. Basic elements of field olfactometer.

composting facilities function in underpressure in order to limit emission. The waste disposal area is equipped with degasification system which limits its emission impact to the active disposal area. Intensive composting lasting at least 21 days begins after 12 of these tunnels are completely filled with organic waste (the remaining 2 are held in reserve). After this process is completed the product is deposited in the compost storage area (app. 20 000 m^2) in piles 5 m wide and 2.4 m high, where it matures for 8–10 weeks. During maturation, the compost is turned at least once a week in order to inhibit anaerobic processes which lead to the generation of methane and odorous substances. In a report prepared by an independent company and commissioned by the operator of the landfill in November 2014 the overall emission from the compost maturation area was estimated at several million $ou_E\,s^{-1}$ (Kabulski et al., 2015). The emission is higher in the early phase of maturation. The two main emission sources were identified as waste disposal area and compost storage area, both of which are area sources with fugitive emission and time variable character. The emission from the storage area depends also on the maturation phase and processes such as turning and redistribution of stored compost. Time variability of emissions was taken into account during modelling. The research was carried out as a part of an on-going investigation of the municipal landfill's impact on the air quality in neighbouring areas.

In order to determine individual odour detection thresholds of the panellists, a preliminary test was conducted using aqueous solutions of n-butanol according to the standard procedure developed by St. Croix Sensory, Inc. (St Croix Sensory Inc., 2006). The target inhalation rate was factory-fixed at 16–20 L min^{-1}. Four panellists (2 female, 2 male, aged 24 to 28) were chosen from a group of 20 volunteers. Each participant was given a separate Nasal Ranger field olfactometer (St. Croix Sensory, Stillwater, MN). Odour concentration measurements were performed four times a month from March 2016 to August 2016 and from January 2017 to May 2017 on randomly chosen days, unless there was precipitation, in which case subsequent days were chosen. Location of the five measurement points situated along the landfill's perimeter is indicated in Fig. 4. Measurements were taken simultaneously by all panel members in triplicate. Additionally, ambient temperature, wind speed and direction and relative humidity were recorded. The data from field olfactometry measurements is available in the supplementary material (see Table S1 and Equations S1-S3) (Byliński et al., 2017; St. Croix Sensory, 2008). Meteorological data was registered using a weather station (Vaisala, Vantaa, Finland) located in the vicinity of the landfill. The information regarding the average temperature, humidity and wind speed and direction in the area in which the landfill is situated is shown in Fig. 2.

2.2. Odour dispersion modelling

Odour dispersion was calculated using non-steady-state Lagrangian Gaussian puff model CALPUFF v. 7.2.1 with dedicated meteorological pre-processor CALMET v. 6.5.0 (U.S. EPA - United States Environmental Protection Agency, 2016). This model includes such parameters as land use, terrain elevation (Fig. 3) and spatially and temporally variable meteorological data. Input data for CALMET were generated using the WRF v. 3.7.1 mesoscale numerical weather prediction system (Skamarock et al., 2008) with a 5 km resolution, and the output was in the form of meteorological fields in a 0.5 km grid.

Both meteorological parameters and odour concentrations were modelled in a 15-km radius from the landfill (68 × 64 grid). Odour concentrations were calculated in discrete receptors situated 1.5 m above the ground in a 0.5 km grid. High grid resolution was necessary in order to model the impact of complex topography on dispersion. Odour concentrations were calculated with 1-h time resolution. The obtained data was the basis for determination of statistical parameters for further analysis.

2.3. Urban planning outlines

The results of odour dispersion modelling were juxtaposed with the location of residential development in the area and the existing local planning structure represented in local land use plans (UMG, 2017). These are basic local planning acts in Poland in which described is the permitted land use and conditions of its development. The data from olfactometric analysis and odour dispersion modelling was then used to draft proposed planning outlines for the further spatial development of the area aimed at reducing the impact of odour nuisance.

3. Results and discussion

3.1. Results of odour dispersion modelling

Odour threshold (OT) of 1 ou m^{-3} is commonly used as a criterion in odour nuisance assessment. However, in order to determine the actual impact of odorous substances emission over an extended period of time, it is convenient to predict the total amount of time during which threshold value is exceeded. Since at present in Poland there are no regulations outlining air quality standards relating to odours, threshold values are usually based on the legislation of other EU countries or on a draft bill “Odour Nuisance Prevention” prepared by the Polish Ministry of the Environment. In the latter, it is proposed that odour threshold can be exceeded in no more than 3% of year's hours, that is 262 h (Department of Air and Climate Protection of the Polish Ministry of the Environment, 2016). The assessment of the municipal landfill's odour impact was based on two parameters, namely maximum odour concentration during exceedance of threshold values (Fig. 4), and the number of year's hours in which the threshold was exceeded (Fig. 5). Emission factor estimation was based on field olfactometry measurements in conjunction with reverse modelling. The use of data analysis enabled to estimate the emission rates for each area source, with 78.6 ou $m^{-2}\,s^{-1}$ and 1.5 ou $m^{-2}\,s^{-1}$ from compost storage area and waste disposal area, respectively.

Based on the modelling the odour impact was strongest (>10 ou m^{-3}) within a maximum radius of app. 2 km to the North and app. 1 km to the North-East from the landfill perimeter. Maximum radius of odour threshold exceedance area was app. 4 km to the North, 5 km to the East and 2 km to the South and West from the landfill, encompassing parts of residential areas in the southern districts of Gdańsk. Odour concentration levels were higher during night time due to more stable meteorological conditions which impedes the dispersion of pollutants.

A similar range of impact was determined during the analysis of odour threshold exceedances frequency. Odour concentration was higher in the eastern direction, where in the radius of 2 km from the landfill odour threshold was exceeded in 15% of year's hours.

3.2. Spatial planning outlines

The municipal landfill became a source of major nuisance in 2011 after an open composting plant was created in compliance with European regulations. Residential development continued to expand in the direction of the landfill, as indicated in Fig. 4, despite the frequency of odour incidents. This was not prevented by the means of local land use plans, the structure of which does not reflect the discussed environmental issue dominant in the area. Moreover, in none of them the issue of odour dispersion is

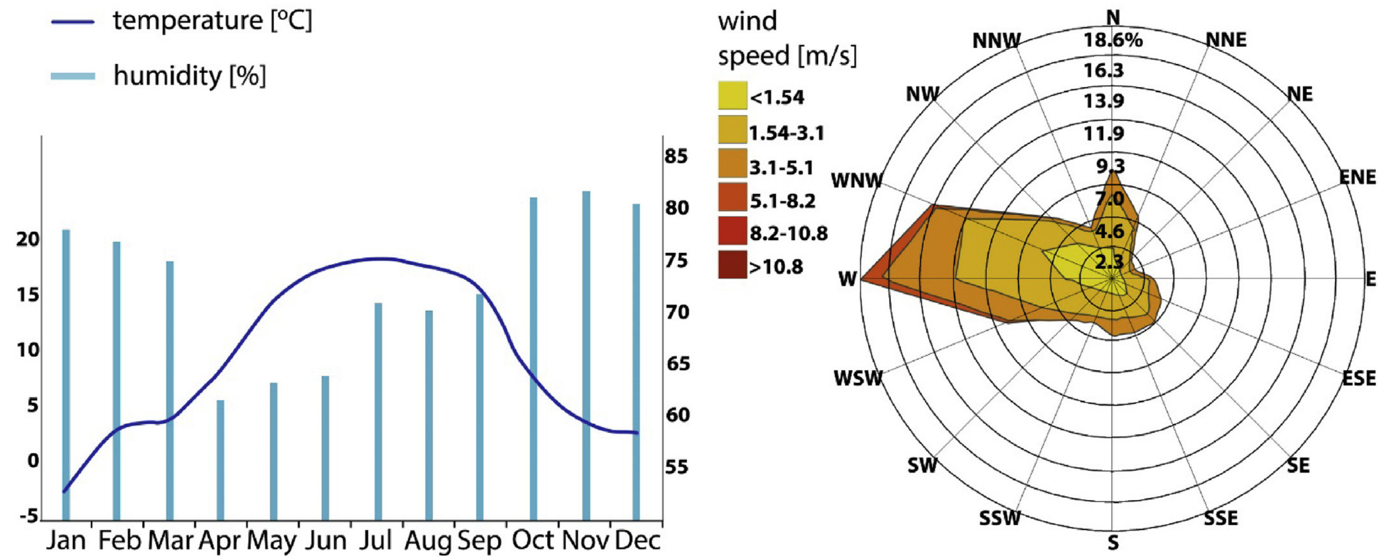

Fig. 2. Average humidity, temperature, and predominant wind speed and direction at the location of the communal landfill.

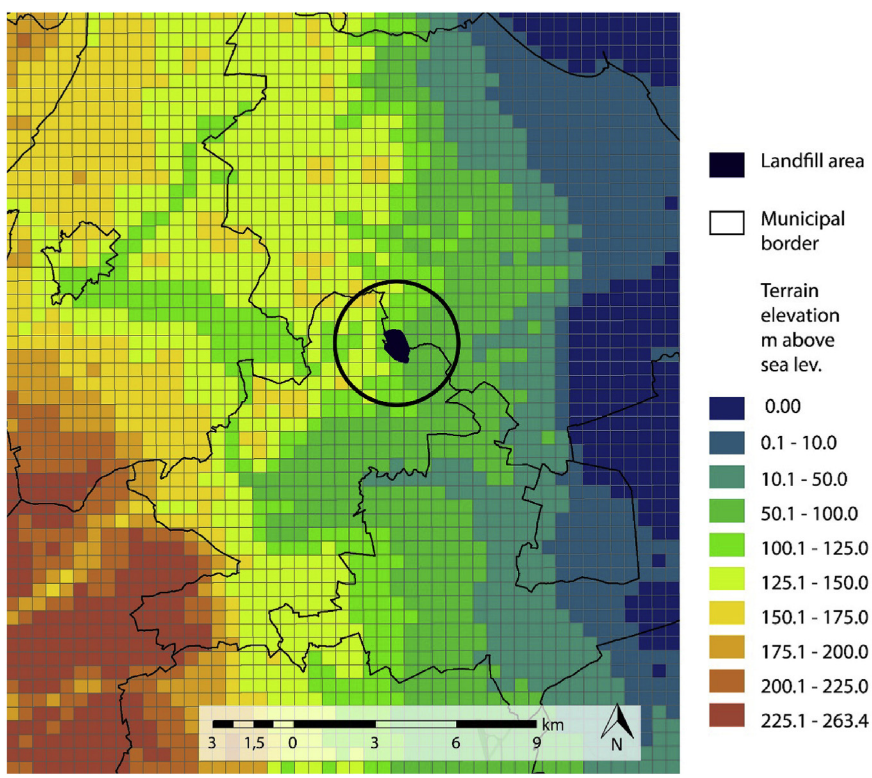

Fig. 3. Terrain elevation above sea level in the area of analysis.

mentioned nor are spatial strategies for odour mitigation. In the proposed approach results of odour dispersion modelling were used in the local urban planning process in order to provide outlines for further development as well as solutions for the improvement of the existing conditions. Several spatial strategies may prove helpful in limiting the odour dispersion.

According to Nowak et al. (2006), trees may be used to remove airborne pollution as gaseous substances are absorbed via leaf stomata or cumulated on their surface and then transferred into the ground by rainwater. Vegetative environmental buffers which are vegetation systems intended to redirect winds or reduce their speed introduced near the source of malodour have been proven to be successful in reducing its impact (Tyndall and Colletti, 2007). These can take the form of shelterbelts and windbreaks. Several factors should be considered in their design, e.g. vegetation height and density, predominant wind direction and source orientation (Parker et al., 2012). The existing fragmentary tree belt around the landfill provides only partial protection and was not planted in relation to the predominant wind direction and thus requires further development. Another solution is to introduce areas which

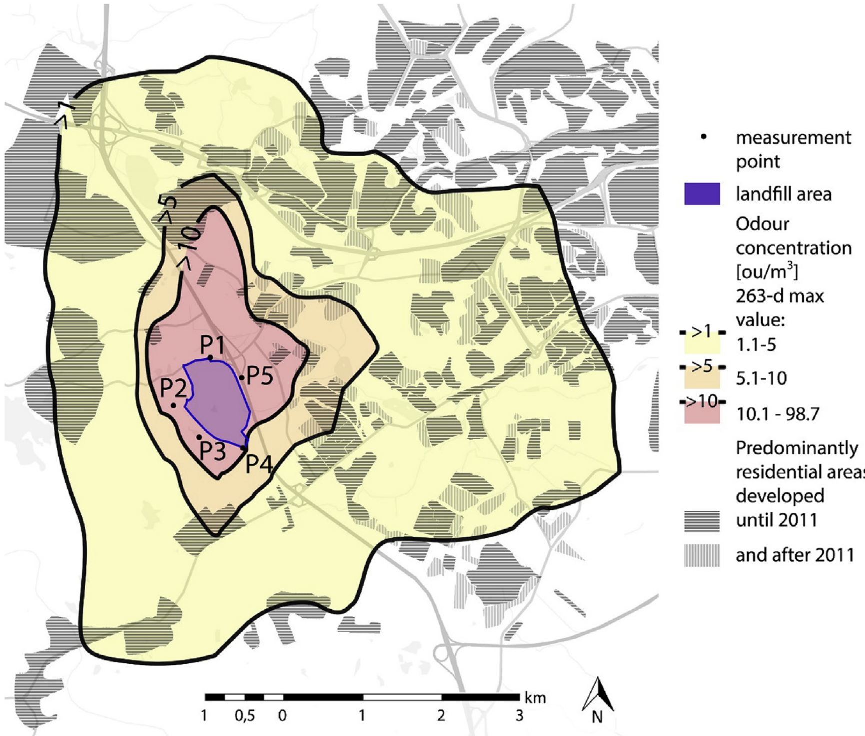

Fig. 4. Location of measurement points along the communal landfill's perimeter, areas of odour threshold exceedance [ou m^{-3}] and the spatial distribution of predominantly residential areas before (dark grey) and after (light grey) the year 2011.

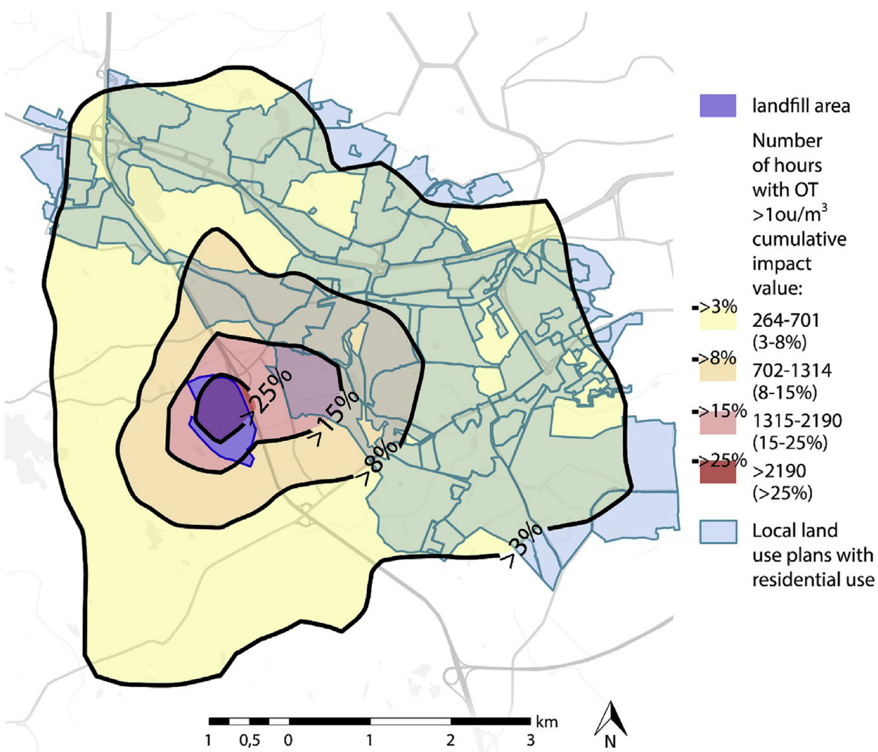

Fig. 5. Areas indicating the number of year's hours in which the threshold of ou m^{-3} was exceeded projected on the outline of local land use plans in which residential use is dominant or complementary.

should be excluded from further residential use unless the odour issue is resolved. Instead, light industry or commercial uses should be introduced on the site within the range of odour dispersion. Since the results of odour dispersion modelling are a comprehensible and clear spatial representation, the outline of such zoning is easy to draft. An example of the above-mentioned outlines for local planning strategies is shown in Fig. 6.

As the discussed land use planning system depicted in Fig. 5 is incidental and fragmentary, failing to convey a coherent vision of spatial development and ecological protection, there is a growing need to develop integrated urban planning system aimed at reducing urban dispersion and incidental mixing of conflicted functions as well as at achieving the principles of sustainable development and environmental objectives. However, it should be noted that land use planning is only a tool for ensuring the consistency and continuity of urban policy and land development (Jones et al., 2005) and should not replace the horizontal urban governance process. Therefore, the proposed outlines should only be an aid in inclusive decision-making where the spatial master plan is developed with the participation of local community. For example, an Odour Control Master Plan approach was developed and implemented in Fairfax County, VA in the area adjacent to a wastewater treatment facility with the active participation of local community. Odour dispersion model was used to discuss a set of short-term, mid-term and long-term recommendations for odour control improvements to be implemented by the operators of the wastewater treatment facility (Easter et al., 2009).

Bringing social participation into the process of environmental governance is an important factor in improving awareness and promoting the principles of sustainable development. As the form and functioning of urban environment depend, among others, on the social system of values and its local conditioning, the participation of urban residents, quality of legislation and on the effectiveness of local authority institutions and other public organisations (Dymnicka, 2009). A theoretical approach based on relational dependencies between architecture, urban design, natural environment and urbanisation are worth attention (e.g. Graham and Healey, 1999; UN-HABITAT, 2011). The widely accepted understanding of the city as a built environment is based on the assumption that its analysis should be conducted in regard to social, cultural or economic issues in which local, regional and global processes are taken into consideration. It is thus important to develop local environmental strategies that are best suited to local problems and the specific conditions of the urban and social structure.

There is substantial evidence suggesting that environmental issues are resolved more effectively and efficiently at the local and regional level (Lipschutz and Mayer, 1996). Environmental norms often inhibit urban growth, whereas improvement of environmental quality is omitted in spatial planning or incorporated at a late stage (Runhaar et al., 2009). As it was suggested by Wong et al. (2011) in the context of urban microclimate, environmental evaluation data should be used in the master planning process, integrating various models into a common platform. Therefore, it is important to note that odour nuisance is just one of many aspects to be included in the planning process. Similarly, other environmental quality evaluation parameters should be taken into consideration, for example, noise pollution (Zannin et al., 2013).

4. Conclusions

Odour dispersion modelling based on data obtained using field olfactometry can be a valuable tool in the process of local spatial planning. Field olfactometry is useful for determination of odour quality of air in a quantitative manner. The results obtained using this technique can be used as input variables in odour distribution modelling which provides valuable spatial and temporal data in a form accessible to the urban planners. As demonstrated in the presented case study, the results of sensory analysis may be useful in creating guidelines for spatial strategies of odour nuisance reduction in urban residential areas. When there are no state-level regulations of odour emissions, the issue of odour nuisance's

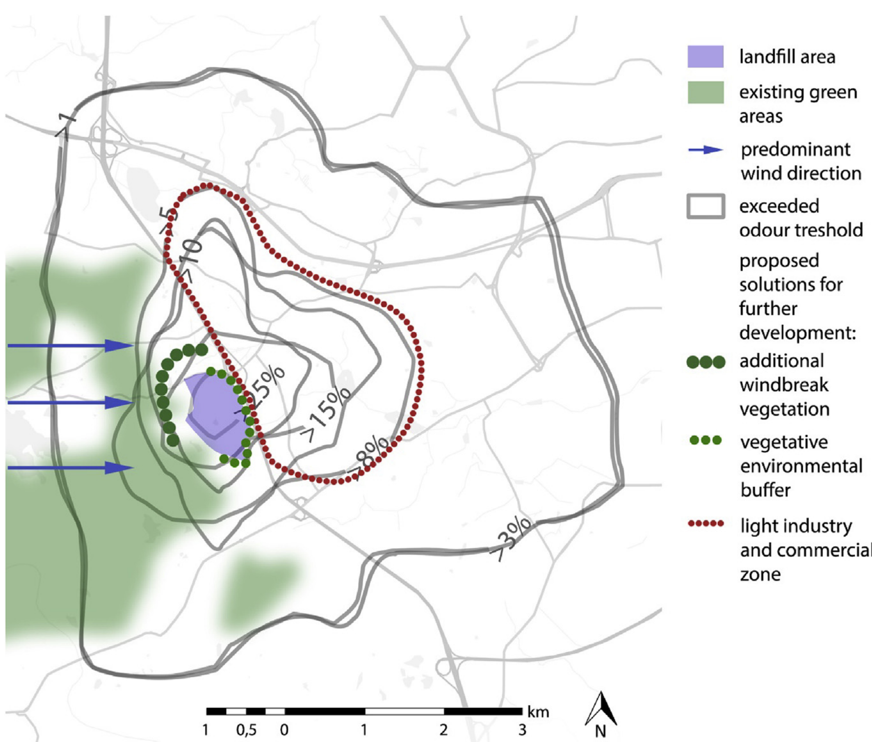

Fig. 6. Proposed outline for local planning strategies based on odour dispersion modelling data.

impact can be tackled at the level of local spatial planning when data obtained using analytical techniques is available. Such approach can be further used in other urban contexts in which evaluation of environmental quality is necessary, e.g. in high-density urban areas or in the re-development of post-industrial sites.

Exposure to malodour should be an important factor in urban areas management and planning due to its detrimental effect on human well-being and quality of life as well as its role in the social creation of space. An interesting aspect for further research may be the implementation of evaluation of other aspects of environmental quality into integrated urban planning. However, environmental quality assessment should not be used merely to facilitate top-down decisions and provide threshold values for regulations. It can also be utilised at the level of local planning to aid the process of collective decision-making. The objective should be to achieve both the best quality of life in a social, economic and ecological dimension and to increase civic participation into environmental problems.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jenvman.2018.02.086.

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