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Odour Nuisance As a Consequence of Preparation for Circular Economy

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Abstract:

Purpose: *The main objective of this article is to assess the intensity of odour nuisance in urban areas, as resulting from the current solid waste disposal management policy.*
Design/Methodology/Approach: *During the study severaal parameters were evaluated: in-situ odour concentration using the NasalRanger method (expressed in ouE/m3), hedonic odour sensory quality and description of odours using predefined descriptors (the list of descriptors included 109 items). For the purpose of evaluation of the hedonic sensory quality, a five-point scale was used in accordance with VDI 3883 recommendation: 1-pleasant, 2-neutral, 3-unpleasant, 4-very unpleasant, and 5-extremely unpleasant.*
Findings: *The analysis of the results has confirmed a considerable impact of the average air temperature on the occurrence of odour nuisance.*
Practical Implications: *A solution that may translate into the reduction of odour nuisances in urban areas is a closed-loop economy, which has become an important issue for the future and competitiveness of enterprises. Reuse and recycling of materials are two of the main characteristics of a closed-loop economy.*
Originality/Value: *On the basis of the conducted sensory tests it is plausible to state that the smell nuisance depends on numerous factors.*

Keywords: *Circular economy, quality of life, odour nuisance, life comfort.*

JEL Codes: *Q01, L22, Q51, Q53, Q56.*
Paper type: *Research article.*

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1. Introduction

According to the conceptual framework of the Circular Economy (CE), products, materials and raw materials should remain in the economy as long as possible and solid waste output should be minimised to the greatest possible extent. Solid waste - if it has already been produced - should be treated as recyclable materials (Schreck and Wagner, 2017). This concern is particularly important in view of the negative consequences of linear economy, i.e. increasing amounts of outstanding solid waste resulting in the necessity of its storage and landfills located near urban agglomerations, which causes deterioration of the quality of life, e.g. due to the emerging odour nuisance (Blanes-Vidal *et al.,* 2012; Cliffe-Byrnes and O'beirne, 2010; Di Gilio *et al.,* 2018; Gou, Lau and Lin, 2017; Mirabelli *et al.,* 2006; Muižniece-Treija, 2017; Wing *et al.,* 2008; Wolkoff, 2018).

The presence of fragrance compounds in ambient air is a serious problem, especially for the inhabitants in areas adjacent to industrial plants (Carrera-Chapela *et al.*, 2014, p. 40) and especially the plants involved in landfilling and wastewater treatment. Fragrance compounds may impair the quality of life by causing symptoms associated with long-term exposure, including headaches, nausea, concentration problems, and loss of appetite, stress, insomnia and discomfort. Fragrance irritation has an adverse impact upon the residents of communities in the areas neighbouring persistent onerous industry (Byliński, Gębicki and Namieśnik, 2019). In most cases, the adverse impact of fragrances is not related to their toxic effect on the organism but results from the individual subjective perception and assessment, which in the long run negatively affects the human psyche. For this reason, air pollution associated with the presence of fragrance substances is referred to as odour nuisance.

Compared to other forms of air pollution, exposure to odour resulting from human activities is generally considered a nuisance instead of a threat to public health or natural environment. Unlike noise pollution, the measurement, regulation, and impact on human health of which is well known, the issue of odour nuisance is not sufficiently governed (Sucker, Both and Winneke, 2001, p. 44). However, interest in the health consequences of unpleasant odour has increased in recent decades, often as a result of exposure of residents to 'nuisance industries' such as urban wastewater treatment and solid waste disposal facilities, sewage sludge applications, industrial animal farming, and the production, storage and transport of industrial chemicals (Schiffman and Williams, 2005).

Fragrance characteristics and measurement have become very important environmental issues due to increasing public awareness of the environment and the impact of air quality on health and well-being (Nicell, 2009). Therefore, fragrances have been the subject matter of many cross-sectional, cross-functional studies in recent years (Buettner, 2017; Croy, Nordin and Hummel, 2014; Zucco *et al.*, 2014). Research areas include, among others, the research on the identification of factors influencing the recognition and evaluation of fragrances by humans (Greenberg, Curtis and Vearrier, 2013) as well as the evolution of methods, techniques and views on fragrances as an air component (Gruber, Jutze and Huey, 1960; Kerka and Kaiser, 1958). Recognition of fragrances has been enhanced, accounting for more effective identification methods and measurement techniques. As a result, attempts have been made to create universal standards and evaluation criteria (van Harreveld, Heeres and Harssema, 1999).

At present in Poland there are no clearly defined methods of measuring odour concentrations for the purposes of assessing the odour impact of objects. The complex interrelation between individual olfactory sensitivity of individuals and the concentration of respective chemical compounds in the air, their type, meteorological and topographical conditions affecting the distribution of odour give rise to numerous disputes and discussions in the scientific community concerning the adoption of an adequate methodology for measuring odour nuisance purposes. Currently, only the method of dynamic olfactometry is legally binding in our country in the form of PN-EN 13725:2007 standard, Air Quality - Determination of Odour Concentration by Dynamic Olfactometry (Szakiel, 2018).

Due to population density, location and concentration of odour sources and the number of affected individuals, the problem of nuisance mainly concerns urban areas (Pedersen, 2015). Watercourses (Sado-Inamura and Fukushi, 2018) and urban sewerage (García *et al.,* 2017; Zhu *et al.,* 2016) are important sources of urban fragrances. These sources are the subject of studies not only on the chemical composition of liquids but also on the composition of odour emitted by them (Zhu *et al.,* 2016). Additional sources of smell in urban areas are increasingly being fumes (Cernansky, 1983), biomass (Freiberg *et al.,* 2018) or fragrances from closed surface equipment, such as offices, which may affect the quality of work and health of employees (Wypych, 2017), and fragrances from landfills or composting plants. Fragrances are not only an element of man's biological environment but also a cultural factor related to both the creation of fragrances in the course of man’s activities and the influence on human relations (Hoffmann, 2013; Marsousin and Khodadadi, 2015; Okulicz-Kozaryn and Valente, 2019).

It should be noted that the final assessment of fragrance is influenced by many factors, the most important of which are, among others, the perceived intensity of fragrance impression and emotional load associated with reception of fragrance, which is influenced by factors related to upbringing, cultural and social conditionalities.

Taking the above assumptions into consideration, the main objective of the article has been to assess the intensity of odour nuisance in urban areas, as resulting from the current solid waste disposal management policy. In order to achieve the main objective, studies were carried out on odour concentration determined by means of field olfactometry using the NasalRanger olfactometer and the assessment of hedonic quality of existing odour.

2. Materials and Methods

2.1 Selection of Research Method

Among the methods of assessing air odour nuisance, two main groups should be distinguished: sensory methods and analytical methods. The specificity of the odour perception process causes the sensory methods of assessing odour nuisance to serve the basis for the assessment of odour nuisance. The interrelation between the concentration of individual chemical compounds in the air, their type, meteorological conditions, and topographic conditions influencing the distribution of odour, individual olfactory sensitivity of individual compounds and the perceived intensity of olfactory sensation is not a constant value but may only be assessed sensorially.

Among the methods of sensory evaluation of olfactory concentration, static olfactometry, dynamic olfactometry and terrain olfactometry may be distinguished. The static olfactometry method (Cheng *et al.*, 2019) consists in static dilution of the collected air sample and presentation of the previously prepared test samples to evaluators.

The second method used for sensory assessment of odour concentration is indirect dynamic olfactometry (Rincón *et al.*, 2019; Hove *et al.*, 2017; Klarenbeek, Ogink and van der Voet 2014; Zhang, Feddes and Zhou 2002; Giungato *et al.*, 2016). In this method, like in static olfactometry, it is necessary to take a sample at the place of testing and deliver it to the laboratory.

In this study it has been decided to use dynamic field olfactometry, which allows for measurements of odour concentration directly at the site under consideration. This method uses a relatively inexpensive Scentoid SM100 or Nasal Ranger equipment (Badach *et al.*, 2018; Walgraeve *et al.*, 2015; Pan, Yang and DeBruyn 2007) to dilute the existing air with filtered air through carbon filters integrated in the equipment. The measurement is carried out from the highest dilutions and in each step the dilution is reduced until an individual threshold is reached for the existing odour. The result is then calculated as the geometric mean of the odour concentration corresponding to the lowest dilution that causes the odour to be detectable, and a higher degree of dilution.

2.2 Testing Context

The issue of odour nuisance is not governed by law in Poland; there are no standards and procedures, so it is often difficult to establish even such an important problem as who is to deal with the issue of odour nuisance, i.e. which state administration institution is responsible for monitoring the environment. Moreover, the location policy is not governed by law either, which means that industrial areas are located near residential areas (see the figure below, we will insert a map showing the location of mixed areas and industrial plants).

The research was conducted in the south-eastern part of Kraków (Płaszów region). This region is characterised by the highest growth of urbanised areas and changes in the spatial development of the areas of the municipality of Kraków. Odour-related issues constitute a serious problem for the inhabitants of Płaszów, often reported to institutions monitoring environmental protection. The significance of the problem is confirmed by, for example, the Internet diary describing the smell nuisance in the form of reports of the residents and the content published on the Internet forums describing the complaints about the smell nuisance.

2.3 Distribution of Sampling Points

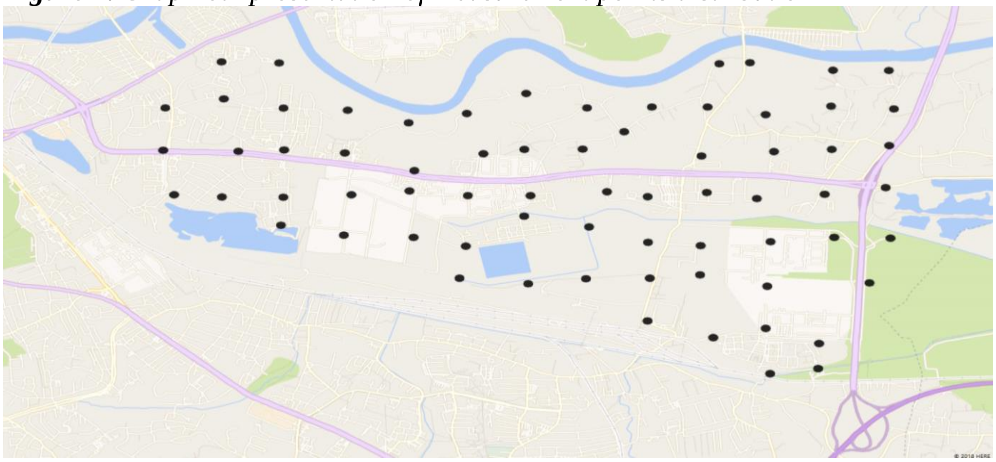
Studies on the smell nuisance of the Płaszów area in Kraków were conducted in the period from the beginning of September till the end of November 2018. The distribution of measurement points conformed to the requirements of VDI 3940 part 1 standard concerning the methodology of field measurements of the odour quality of air. This standard has been developed by the German association of engineers and is commonly used in European countries. The recommendations of the standard provide for the assessment of the odour nuisance of a single, well-known object, therefore it has been necessary to adapt the recommendations to a much more complex system, which has been the case with the study area of Płaszów-Rybitwy.

Measurement points were evenly distributed throughout the area. The applied method of distribution of the points allowed for the assessment of the odour air quality in the whole study area, at the same time indicating potential locations of odourant emission. For the purposes of the study, 69 measurement points were finally determined, and the distances between the points were 500 m. The study was conducted in the evening hours, i.e. between 18:00-23:00.

Meteorological parameters were obtained using the portable meteorological station Davis 6250 Vantage. During the study period, the prevailing winds were blowing in the east-west axis, with a very small share of northern and southern winds. A constant tendency of temperature drop was also visible, thanks to which the study covered the period characterised by medium and low temperatures occurring in this region.

Initial reconnaissance of the area showed the occurrence of at least 7 identified objects that could be the source of odour nuisance, but it could not be ruled out that there were nuisance objects in the study area that had not been identified before the study. Therefore, the measurement points were evenly located in the whole study area, without maintaining the recommended central location of the facility, which was a potential source of odour emission. The applied method of distribution of the points allows for the assessment of the odour air quality in the whole study area, at the same time indicating the potential locations of odourant emission.

Figure 1. *Graphical presentation of measurement points distribution*



2.4 Test Methodology

2.4.1 Selection of parameters to be analysed

During the study, a total of 3 parameters were evaluated: in-situ odour concentration using the NasalRanger method (expressed in ou_E/m3), hedonic odour sensory quality and description of odours using predefined descriptors (the list of descriptors included 109 items). For the purpose of evaluation of the hedonic sensory quality, a five-point scale was used in accordance with VDI 3883 recommendation: 1-pleasant, 2-neutral, 3-unpleasant, 4-very unpleasant, and 5-extremely unpleasant.

According to the guidelines contained in the EN 13725 standard, field tests were performed by a team of four panelists, who, according to the ISO 8586 standard, had the status of selected assessors. In the course of the study, 516 assessments of all the parameters indicated by a 4-person team were carried out, resulting in a total of 1548 unit results for each of the parameters. Due to the results obtained in the previous survey conducted in the same area, the studies were conducted in the evening (18-23), which had been indicated by the respondents as the hours of occurrence of the greatest odour nuisance.

2.4.2 Preparation of the team for sensory evaluation

Qualification tests for the sensory team were conducted in the sensory research laboratory of the University of Economics in Kraków. The procedure of recruitment and selection of candidates for the evaluation team that carried out field markings had been based on the requirements of standards (ISO 13300-1: 2006; ISO 13300-2:

2006; ISO 8586 2012; ISO 4121 2003; ISO 11035 1994; ISO 4120 2004; ISO 8587 2006; ISO 5496 2006; ISO 13301 2018) and related literature (Stone, Bleibaum and Heather, 2012; Kemp, Hollowood and Hort, 2009; Rogers, 2018; Meilgaard, Carr and Civille, 2006).

A total of 54 assessors, evaluators were recruited. The initial stage of recruitment was to assess the ability to rank n-butanol samples of varied intensity. Five samples were prepared and, the task of the evaluators was to rank them according to increasing intensity. The critical value of the Spearman's Rank Correlation Factor (which translates into the ability to order the samples correctly) was set at 0.7. Out of the 54 individuals who had been qualified for the evaluation, 23 achieved Rs results greater than or equal to 0.7. These individuals were interviewed and presented a plan of subsequent training sessions and the need for disposal during the entire session of measurements. Finally, 15 people applied for detailed training and further testing of sensory sensitivity, however, three more people resigned during the training.

Each of the selected assessor met the requirements of the EN 13725 standard for an individual sensitisation threshold for n-butanol. During the training sessions in the sensory laboratory, each of the assessors had the opportunity to familiarise themselves with the Nasal Ranger (NR) portable olfactometers and to learn how to inhale correctly so that the suction rate was within 16-20 l/min. The team also had an opportunity to familiarise themselves with selected chemical fragrances representing different groups of fragrances: Trimethylamine, Dimethylsulflde, Butanoic acid, Acetic acid, Ethyl acetate, Styrene, Benzaldehyde, CedryI acetate, Geosmin, lsobutylquinolein, Benzothiazoles, 2-Phenylethanol, cis-3-Hexen-1-ol. The Odour Sensitivity Test Kit (St. Croix Sensory) was used during training and testing. The total training time for each of the selected assessors was 80 hours.

3. Test Results

On the charts, apart from the list of averaged values of individual parameters in the studied months, the location of plants that may cause odour nuisance in their surroundings is also presented. In order to improve the readability of the charts, the location of plants was marked with numerical symbols in accordance with the following list. The names of the facilities are presented in accordance with the main activity profile:

1. sewage treatment plant;
2. composting plant;
3. leather processing plant;
4. solid waste disposal facility;
5. commercial complex - direct sale of agricultural products;
6. solid waste disposal management and recycling;
7. solid waste disposal management and recycling.

Figures 2-4 show the fragrance concentration determined by means of the NasalRanger method in 3 consecutive months. The green areas are characterised by average odour concentrations not exceeding 5 ouE, which is considered a limit value. The yellow colour indicates areas where odour nuisances are clearly felt, while red or black colour indicates areas with very high odour nuisances.

The values are expressed in terms of fragrance units per unit volume (ouE/m3). One European Odour Unit (ouE) per cubic metre is, according to EN 13725:2007 norm, a concentration of odourant or mixture of odourants that corresponds to the collective odour sensitisation threshold, meaning that at least 50% of the assessors' sense odour at a given concentration. The odour concentration (C [ouE/m3]) is a multiple of the threshold. It is measured by determining the degree of dilution (Z) necessary to achieve it.

Figure 2. *Graphical presentation of average odour concentration marked by NasalRanger method expressed in terms of* $ou_E/m3$ *in September 2018*

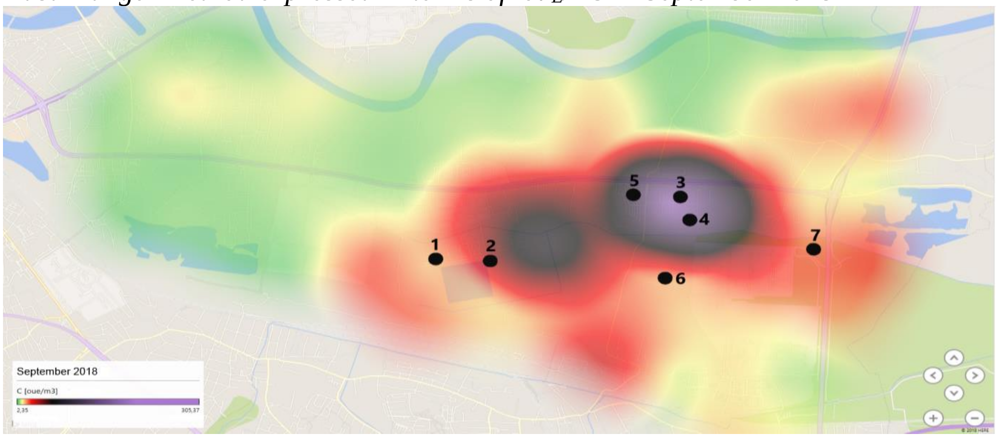


Figure 3. *Graphical presentation of average odour concentration marked by NasalRanger method expressed in terms of* $ou_E/m3$ *in October 2018*

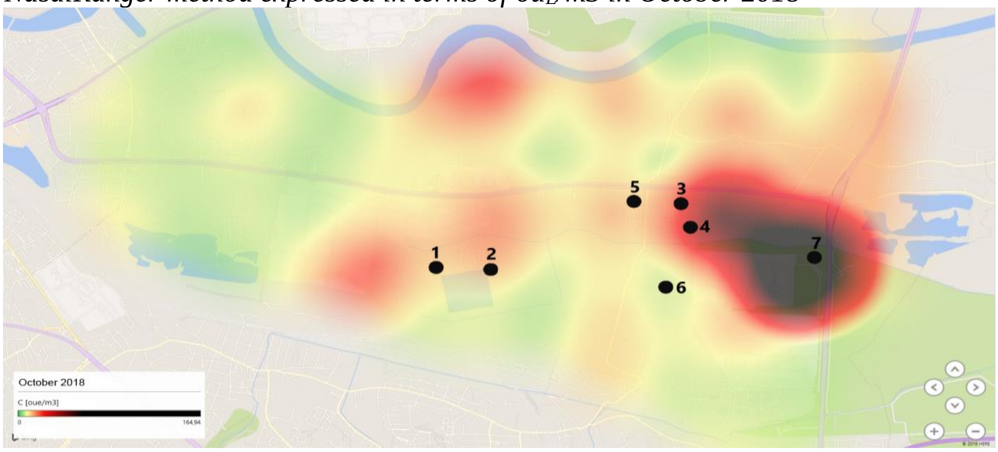


Figure 4. *Graphical presentation of average odour concentration marked by NasalRanger method expressed in terms of ou$_E$/m3 in November 2018*

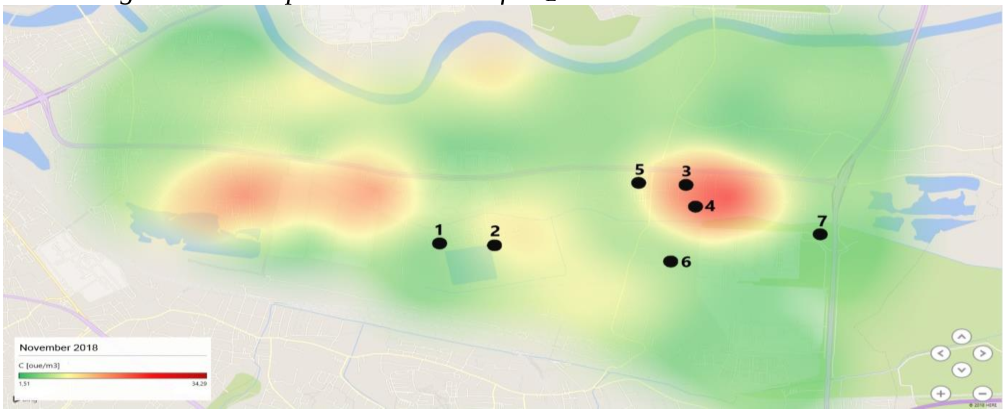


Figure 5. *Assessment of hedonic sensory quality of odour in September 2018*

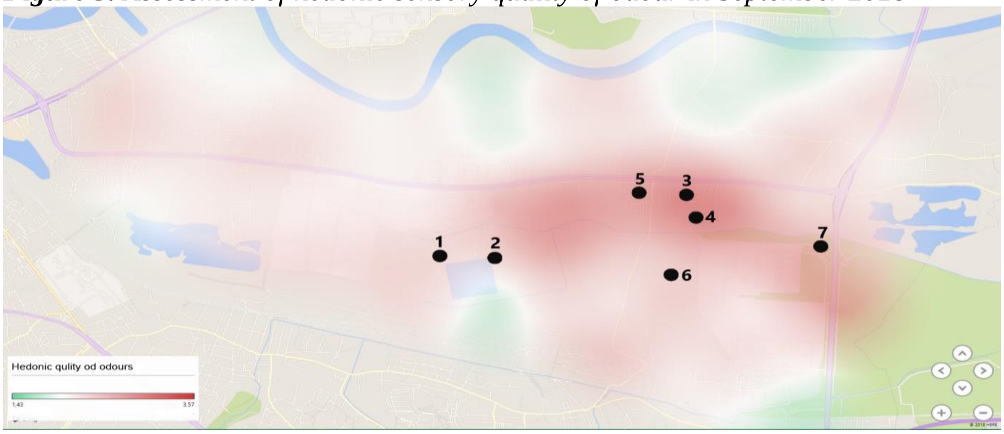


Figure 6. *Assessment of hedonic sensory quality of odour in October 2018*

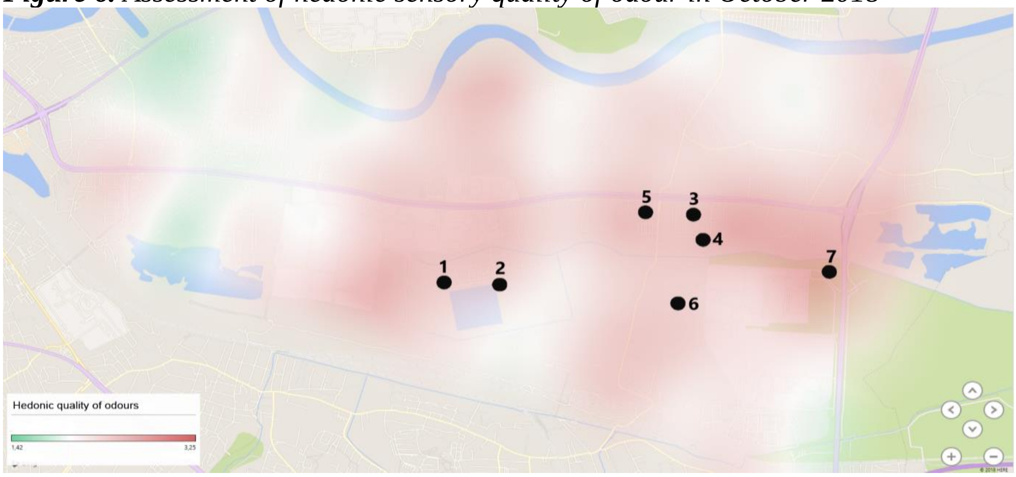
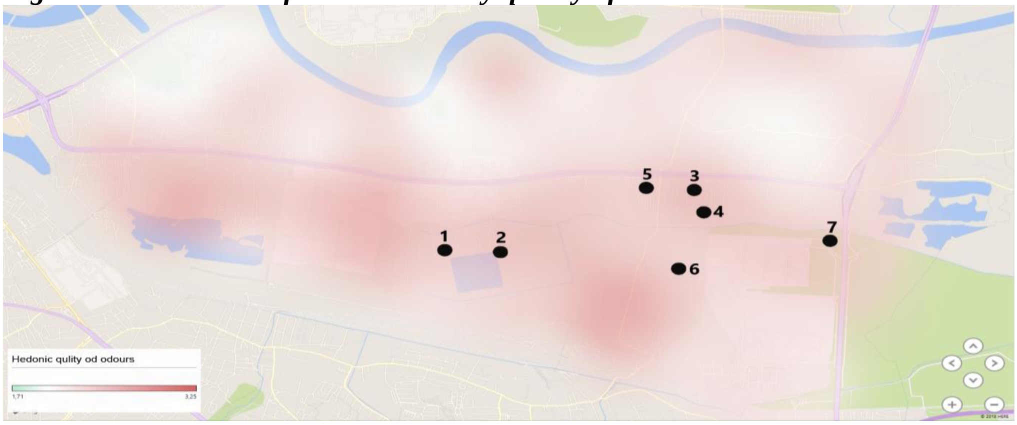


Figure 7. Assessment of hedonic sensory quality of odour in November 2018

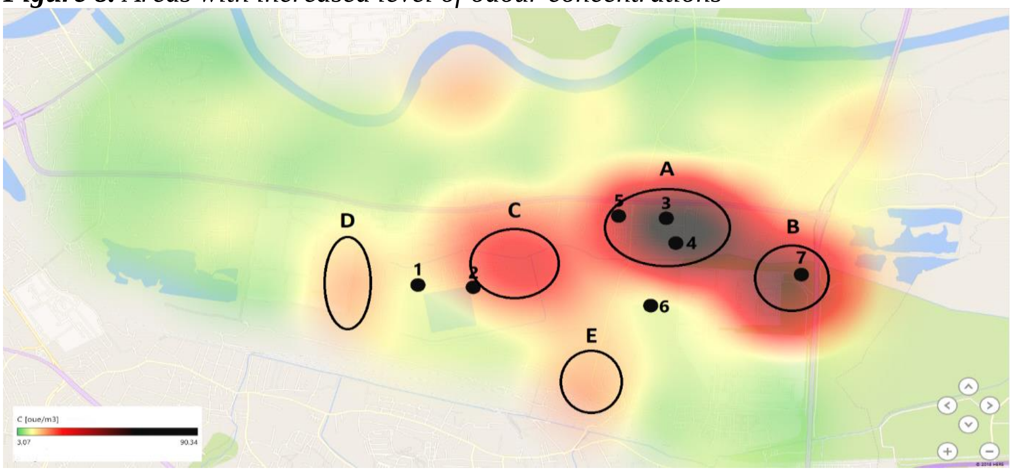


Figures 5-7 present sensory reception of hedonic odour quality in the study area. The green colour indicates areas, where existing odour is pleasant to assessors, the white colour indicates that existing odour is neutral to assessors whereas the red colour saturation indicates intensiveness of negative impressions related to existing odour.

4. Discussion

Analysing the results of the study presented above, one should pay attention to the very large impact of the average air temperature on the intensity of odour nuisance, which decreases with the drop of the average temperature in a given period of time. The average temperature during the survey was 15, 5 °C in September, 11, 8 °C in October and 4, 7 °C in November. The obtained results indicate 5 areas characterised by the increased level of fragrance concentrations and negative evaluation of hedonic sensory quality.

Figure 8. *Areas with increased level of odour concentrations*



The first area, designated by the symbol A, has the highest measured odour concentrations. The location includes leather processing plants (3) and a commercial complex (5).

During the study, the panelists indicated the following types of odour in the area: decay, rot, sour, chemical, dung, rubbish, musty, decayed, rotten eggs. Identified odour does not allow for an unambiguous indication of the source of odour - the nature of odour may indicate that it takes its origin in the facility (3) which has its own sewage treatment plant and from the area (5) where agricultural products are traded, and derived solid waste may cause the formation of some of the identified odour. Due to the distances between the measurement points as arising from the size of the whole study area, it is not possible, however, to indicate unambiguously which of the mentioned facilities located in this area is the main reason for the occurrence of odour nuisances.

The second defined area of odour nuisance, marked with the symbol B. In this location there is a facility dealing with solid waste disposal management and recycling (7). The types of odour identified during the study are: rubbish, grass, leachate from the landfill, swamp, manure, burnt plastic and car exhaust fumes. The smell of car exhaust fumes probably results from the immediate vicinity of the expressway, while the smells of grass and marshy grass may come from nearby green areas. The other types of identified odour are quite characteristic of the type of activity carried out by the only solid waste disposal facility in the area, which means that they are most likely to be emitted from the site.

The third defined area, marked with the C symbol. Both the sewage treatment plant (1) and the composting plant (2) are located in this location. During the survey, the following types of odour were identified in this area: rotten eggs, sewage, boggy, musty, grass, faeces, earthy, unpleasant, rubbish, and leachate, decayed, decayed, rotten and acidic. Some of these types of odour are characteristic of the nature of the operations of the sewage treatment plants but the studies also found intense odour from other sources (decayed, rotten, grass, rubbish).

The fourth of the defined areas, marked with the symbol D. Despite the fact that many operators have been located nearby, the identified odour (rotten eggs, sewage, decay, rot and faeces) indicates the origin of these odour from the same sources, the emission of which was felt in the third area (C). Occasionally perceptible odours: rubbish and chemical may originate from surrounding plants.

The last defined area with increased odour intensity, marked with the E symbol. In this area there are many large, micro and small facilities involved in service and processing operations. The odour identified in the area derives from rubbish, coal, decay, burnt plastic and grass and earthy odour. It should be noted that the plant marked as 6 was not included as a smell nuisance despite the fact that the activity profile is the same as the plant marked as 7, i.e. solid waste disposal management and recycling. This may result from the application of a different technological process. At the same time, it serves as a confirmation that even in the case of storage it is possible to deal with the problem of odour nuisance.

5. Conclusions

The sensory research conducted in the period of three months (September-November 2018), including the determination of odour concentrations (using the NasalRanger method), supplemented by the evaluation of sensory intensity and hedonic quality allowed to demonstrate areas with very high odour nuisance. The studies were conducted in autumn months, when the daily average temperature was relatively low, which accounts for the decrease in the rate of occurrence of organic matter decomposition processes and thus reduces the emission of odour compounds. The analysis of the results has confirmed a considerable impact of the average air temperature on the occurrence of odour nuisance.

On the basis of the conducted sensory tests it is plausible to state that the smell nuisance depends on numerous factors: on the one hand, on the type and concentration of a given substance in the air, and on the other hand, on the chemosensorics of the sense of smell that is a receiver of various substances, sensitivity of which is very much varied. While it is possible to isolate and test the most important odour substances in order to determine the interrelation between their concentration and the intensity of the sensation received by man, it is physically impossible to determine such a relationship in the case of a mixture of several various compounds, among which there are both phenomena of synergy and antagonism.

A solution that may translate into the reduction of odour nuisances in urban areas is a closed-loop economy, which has become an important issue for the future and competitiveness of enterprises. Reuse and recycling of materials are two of the main characteristics of a closed-loop economy. A closed-loop business should adopt an industrial approach based on resource efficiency and the use and supply of sustainable raw materials through innovative technologies, innovative methods or new business models (Oghazi; Mostaghel 2018).

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