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The influence of the methods of measuring odours nuisance on the quality of life

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ABSTRACT

Quality of life in urban space has become an increasingly common problem arising from cooperation between various stakeholders, especially in the context of increasing odour nuisance. That is why it is extremely important to know and shape the expectations and perceptions of residents regarding quality of life by accepting the place of residence, especially in the context of the development of cities and urban areas.

The analysis of the previous research has revealed a research gap that results from the imperfections of existing odour measurement methods and the lack of an objective measurement methodology that would allow for objectification of the subjective feelings of people to the extent of perception of unpleasant odours.

The purpose of this article is to verify the hypothesis about the possibility of objectifying the assessment of odour nuisance based on the comparison of quantitative research results based on the opinions of residents and sensory tests. The specific objective is to verify residents' assessments of odour nuisance by an expert team and identify a gap in those assessments.

The analysis of discrepancies gives the opportunity to identify the imperfections of various research methods and look for ways to improve them. The analysis of compliance of results, on the other hand, gives the opportunity to objectify measurements and build a methodology that may be used for the purpose of assessing odour nuisance by various stakeholders.

Systematic measurement of odours in a public space may serve the basis for resolving local conflicts, creating maps of odour nuisance, assessing the attractiveness of places to live, work, spending free time and tourist value, as well as conscious actions of public authorities in shaping local policies in a specific area.

1. Introduction

For many years urbanization has not only been a process of changing the residential structure in various countries in favor of large agglomerations but also a phenomenon causing various side effects that account for the perceived quality of life (Blomquist et al., 1988; Gehrmann, 1978).

In the research on quality of life in urban areas, one can see a tendency to deepen the research at the level of local problems (Gao and Melser, 2016), including adaptation of the QOL index for the needs of small towns (Sridhar, 2019) or adjusting QOL indexes to local conditions (Royuela et al., 2009). Quality of life in urban space has become an increasingly common problem arising from cooperation between various stakeholders (Serag El Din et al., 2013). That is why it is extremely important to know and shape the expectations and perceptions of residents regarding quality of life by accepting the place of residence (Cilliers et al., 2015), especially in the context of the development of cities and urban areas (Szafranek, 2016).

The growing ecological awareness of society means that in recent years interest in the subject of quality of life in the environmental context has clearly increased (Leeuwen et al., 2006). Therefore, air quality and emissions of compounds into the atmosphere are increasingly becoming a source of quality of life assessment in large cities (Blanes-Vidal et al., 2012; Gilio et al., 2018; Mužniece-Treija, 2017; Wing et al., 2008; Alias et al., 2019). There are many factors that have an adverse impact on the perceived quality of life. Odour is more often

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one of those factors. This is not a typical factor only for urbanized areas but more and more often it is the reason for making a choice to remain in or move from the current place of residence.

It is emphasized that the human nose is able to distinguish about 10 thousand scents (Zucco et al., 2014), and the human sense of smell is one of the important tools for identifying environmental factors as well as collecting information about it and, as a consequence, analyzing it. The human sense of smell is an integrated system of action (Mori and Manabe, 2014) and is considered a separate memory subsystem (Herz and Engen, 1996; Green et al., 2018). Odours affect everyday life (Cowart, 1989), which is why they have become the subject matter of numerous cross-sectional studies on factors influencing recognition and evaluation of odours by humans (Croy et al., 2014; Greenberg et al., 2013). Quality of life in urban space has become an increasingly common problem arising from cooperation between various stakeholders (Roukouni et al., 2018; Bond et al., 2020). That is why it is extremely important to know and shape the expectations and perceptions of residents regarding quality of life by accepting the place of residence, especially in the context of the development of cities and urban areas (Cilliers et al., 2015).

Cross-cutting articles, that have been published since the 1950s (Gruber et al., 1960; Kerka and Kaiser, 1958). Nowadays, many authors recognize the relationship between odours and their emission sources and their impact on people's quality of life (Croy et al., 2014; Wijk and Cain, 1994; Alobid et al., 2014; Călămar et al., 2018; Eusebio et al., 2017; Heisterberg et al., 2014; Oiamo et al., 2015; Pinto et al., 2014; Sopsuk et al., 2013; Ternesten-Hasséus et al., 2007a, 2007b; Wolkoff, 2018). Along with the development of foreground knowledge on fragrances, methods of their identification and measurement techniques have emerged. As a result the attempts have been made to create universal standards and criteria for their assessment (Harreveld et al., 1999).

Research is increasingly focused on the social behavior of residents and the type of industry located in a given region (Eltarkawe and Miller, 2019) and quality of life perceived to this end (Eltarkawe and Miller, 2018). Such studies are carried out not only for the purpose of determining the factors and sources of odour emissions but also serve the basis for creating alert systems for people living in areas adjacent to industrial areas, that are useful in the case of health hazards or nuisance arising from industrial odour emissions (Brattoli et al., 2016). The inclusion of both standardized tools in the measurement methodology and based on the subjective assessments of respondents in surveys make up a common methodical procedure in examining the health condition of residents. The shift from diagnostic tests to quality of life tests (results), from clinical tests to patient-oriented results (PRO), from objective measures to subjective measures, from one-dimensional features to multidimensional traits and from explicit to hidden traits is so much vivid (Rosenlund et al., 2019). Patient reported outcome measures (PROMs) already constitute a standard approach in quality of life research (QOL) and serve the basis for information systems derived from the Patient-Reported Outcomes Measurement Information System PROMIS (Cella et al., 2007). That approach allows for triangulation of techniques, methods and results, and a more complete assessment of the internal validity of the study (Koster et al., 2016).

The problem of odour nuisance determined the need to verify research methods in this area. The scale of this problem applies not only to urban space but also to areas where population centers, industrial plants and solid waste landfill sites are located - in a close vicinity to wildlife areas that people enjoy to spend leisure time. The importance of this problem today is associated not only with quality and comfort of life but may result in health hazards. This may result in a specific behavior pattern of residents, manifested in a choice to move from the current place of living in such spaces and their attempt to influence public authorities and odour emitters. Such behavior is increasingly taking the form of lawsuits and protest actions. Solving those problems, however, comes across a formal barrier that results from technical and methodological deficiencies that do not allow to measure nuisance. The analysis of the previous research has revealed a research gap that results from the imperfections of existing odour measurement methods and the lack of an objective measurement methodology that would allow for objectification of the subjective feelings of people to the extent of perception of unpleasant odours. The research team has therefore attempted to prepare and conduct the research based on several methods.

The main research problem has been to determine the relation between the odour intensity assessed by the inhabitants and the intensity measured by the sensory team.

The purpose of this article is to verify the hypothesis about the possibility of objectifying the assessment of odour nuisance based on the comparison of quantitative research results based on the opinions of residents and sensory tests. The specific objective is to verify residents' assessments of odour nuisance by an expert team and identify a gap in those assessments. The gap identification is based on: Model within; Model between - time; Model between - point.

The analysis of discrepancies gives the opportunity to identify the imperfections of various research methods and look for ways to improve them. The analysis of compliance of results, on the other hand, gives the opportunity to objectify measurements and build a methodology that may be used for the purpose of assessing odour nuisance by various stakeholders. Systematic measurement of odours in a public space may serve the basis for resolving local conflicts, creating maps of odour nuisance, assessing the attractiveness of places to live, work, spending free time and tourist value, as well as conscious actions of public authorities in shaping local policies in a specific area.

The above statements allow to formulate the thesis that odours have become a key aspect of quality of life. They affect everyday life, and the problem of odour nuisance is increasingly becoming a source of quality of life assessment. In order to present the issue in depth, primary data was obtained in the process of survey and sensory research. The research objective was achieved through the identification, analysis and assessment of factors constituting the source of unpleasant odours as well as the assessment of their nuisance levels for residents. The article compares the results of odour nuisance tests conducted using a questionnaire and dynamic olfactometry - sensory examination.

2. Research methodology

2.1. Stages of research

In order to verify the problem of odour nuisance, surveys were conducted in the first stage, and sensory tests in the second stage. The acquired data provided for verification of the assessments made by respondents and experts and determination of the gap in those assessments (Fig. 1).

2.1.1. Stage 1. Acquiring primary data in the survey process

In the first stage, surveys were conducted, the results of which allowed to assess the odour nuisance among the inhabitants of the study area and to select the places with the greatest odour nuisance as well as to determine the time of odour occurrence. That knowledge allowed to plan sensory tests.

2.1.2. Stage 2. Field sensory tests

Sensory tests were carried out in the subsequent stage. In this research process, field olfactometry was used for measuring odour concentration directly on the spot by means of the Nasal Ranger device (Badach et al., 2018), which allows for dilution of stagnant air with air filtered through integrated carbon filters. The measurement was carried out from the highest dilutions and in each step the dilution was reduced until the individual perceptibility threshold for the existing odour was reached. Individual odour concentration was calculated as the geometric mean, the highest dilution at which no odour was detectable and

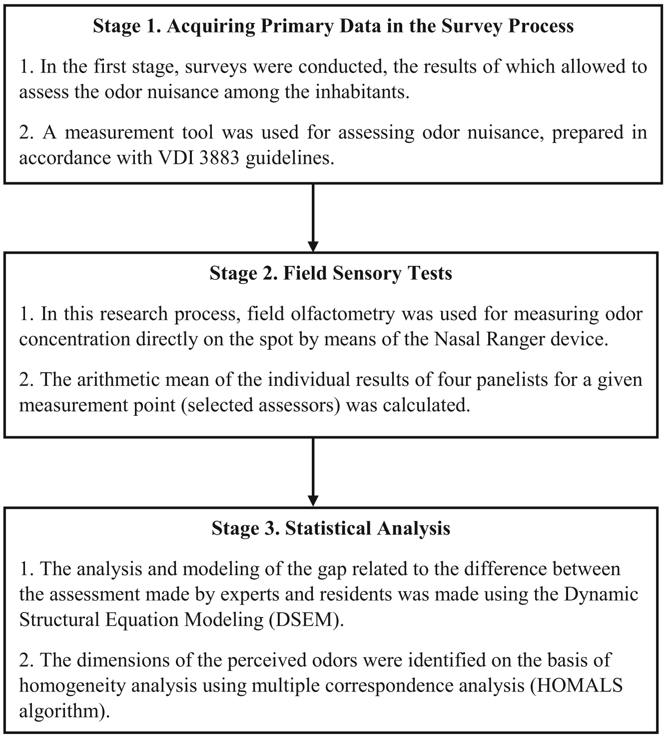

Fig. 1. The research procedure.

the lowest dilution at which it was detectable. Then the arithmetic mean of the individual results of four panelists was calculated for a given measuring point (selected assessors).

2.2. Characteristics of the tested sample

2.2.1. Surveys

(1) Research Tool

The research objective, namely the identification, analysis and evaluation of factors constituting the source of unpleasant odours as well as the assessment of their nuisance levels for residents was implemented by means of the survey method. The questionnaire was developed based on the German research experience (VDI, 1997). Two nuisance scales constituted an important part of the questionnaire, results obtained on both scales. As a result of the performed procedure, the cases in which the difference in indicators was higher than 5 points were removed.

(2) Characteristics of the Tested Sample

The quantitative research covered the residents of one of the districts of Krakow (Płaszów area). The research sample consisted of respondents representing households located in this area, using water supply and sewage disposal services. In this area, according to the data obtained, 21,925 entities used those services. Given the restricted access to respondents and their reluctance to participate in the research, the sample size was finally assumed to include 2000 respondents. After collecting the data and making the initial verification, 1992 correctly completed questionnaires were qualified for the analysis, which with the least favorable structure indicator (50%) gives an error of estimation of 2.09% (Wojnarowska et al., 2020a, 2020b).

2.2.2. Sensory research

(1) Preparation for Sensory Evaluation

Members selection procedures for the panel were based on the requirements of the standard in the sensory laboratory of the Cracow University of Economics:

ISO 4120, 2004. „Sensory Analysis - Methodology - Triangle Test".

ISO 4121, 2003. „Sensory analysis - Guidelines for the use of quantitative response scales". ISO.

ISO 5496., 2006. „Sensory Analysis - Methodology - Initiation and Training of Assessors in the Detection and Recognition of Odours".

ISO 8586., 2012. „Sensory Analysis - General Guidelines for the Selection, Training and Monitoring of Selected Assessors and Expert Sensory Assessors".

ISO 8587., 2006. „Sensory Analysis - Methodology - Ranking".

ISO 13300-1:, 2006. „Sensory Analysis - General Guidance for the Staff of a Sensory Evaluation Laboratory - Part 1: Staff Responsibilities".

ISO 13300-2:, 2006. „Sensory analysis - General guidance for the staff of a sensory evaluation laboratory - Part 2: Recruitment and training of panel leaders".

ISO 13301, 2018. „Sensory Analysis - Methodology - General Guidance for Measuring Odour, Flavour and Taste Detection Thresholds by a Three-Alternative Forced-Choice (3-AFC) Procedure".

A more detailed way of training included in the article Wojnarowska et al., 2020a, 2020b.

(2) Arrangement of Measuring Points

The tests of the odour nuisance of the Płaszów area in Krakow were carried out from September 4 to November 29, 2018.

The measuring points were located in accordance with the requirements of the VDI 3940 part 1 standard concerning the methodology for conducting field measurements of air odour.

Due to the extent of the study area, it was decided to use the maximum allowable size of the measurement grid, in which the distance between the points was 500 m. Finally, 69 measurement points were determined for the purposes of the study.

(3) Season Selection - Sensory Tests

The choice of season and hourly interval for sensory tests was dictated by the results of surveys. It should be noted that the problem of odour nuisance according to the respondents is a year-round problem (Table 1).

The data obtained in the research process allows to state that unpleasant odours are particularly severe in the evenings. As many as 72.04% of respondents think so. According to 45.02% of respondents, odour nuisance is also severe in the afternoon. A similar percentage share proves to be in the "morning" (35.94%) and "at night" (35.18%). In the afternoon hours, the smells disturb the inhabitants of those areas less probably because of their absence due to work.

(4) Selection of Parameters for Analysis Purposes

Table 1
Indications of the respondents regarding odour nuisance in particular seasons.

Season	Percentage of total indications
Spring	21,73
Summer	32,85
Autumn	25,56
Winter	19,86

Source: own research results.

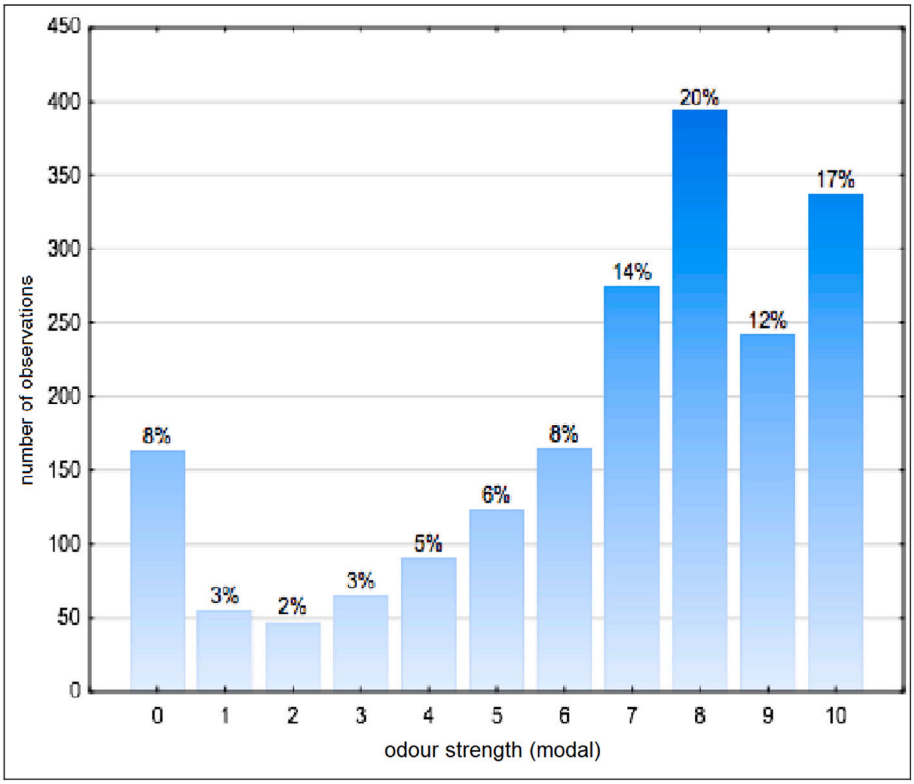

Fig. 2. Odour nuisance strength in the air marked on a graphic scale.

During sensory tests, a total of three parameters were evaluated: the in-situ odour concentration by means of the Nasal Ranger method (expressed in terms of ouE / m^3), sensory odour intensity, sensory hedonic odour quality and description of odours using predefined descriptors (the list of descriptors included 109 items). In the course of the study, 516 assessments of all the parameters indicated by the team were carried out, obtaining a total set of 2064 unit results for each of the parameters (Wojnarowska et al., 2020a, 2020b).

3. Research results

3.1. Perception of odour nuisance

The respondents determined the strength of the unpleasant smell on a graphic scale from "0" (I am not bothered by the smell at all) to "10" (the smell is disturbing, unbearable). In this case the average rating of indications was 6.61, and the median was 7. The most commonly indicated value for odour strength (modal) was level 8, which meant that 20.12% of respondents most often considered that value to be the strength of odour nuisance perceived in the air (Fig. 2).

The respondents most often identified and associated the perceptible odours with the smell of: septic tanks, rot, burning and fumes. Those were the smells that were indicated to be most troublesome. They constituted over 57% of perceived, troublesome odours.

The most commonly identified unpleasant odour was the septic tank smell (32.47%). According to the respondents, the smell of rot (16.31%) and burning (13.79%) were also smelled to be troublesome. Over 9% of respondents were also disturbed by the smell of exhaust fumes, which was the result of increased car traffic volume in the area. Over 10% of respondents indicated to smell an odour that disturbed them outside home (it was irritating in general) but they could not define it. Respondents also indicated a different nature of the odour, describing it as sharp, sweet, smell of garbage, smoke, sulfur, suffocating, bland, smell of rotten eggs, carrion and burned bones.

Bearing in mind the smells that most often bothered respondents outside home, it was also possible to determine, regardless of their percentage share in the overall indications, their degree of distress (the strength of the unpleasant smell) and the strength of the smell usually hovering in the area. "Chemical" smell had the highest average rating in both dimensions. The smell of "rot" and "septic tank" also had a strong odour nuisance on average. In addition to the "chemical" odour, "irritating", "cesspool" and "rot" smells, usually present in the area, were extremely strong on average (Fig. 3).

3.2. Comparison of sensory and survey research

3.2.1. Assessment of odour nuisance intensity on the basis of surveys and studies carried out by the sensory team

The names of the facilities are presented in accordance with business profile.

1. wastewater 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.

The odour concentration from the 3-month study was determined by the Nasal Ranger method (Fig. 4). The values are expressed in odour units per unit volume (ouE / m3) in accordance with EN 13725, 2007. The odour concentration (c_{od} [ou_E/m^3]) is a multiple of the threshold. It is measured by determining the degree of dilution (Z) necessary to achieve it (Tables 2 and 3).

In order to determine whether there are differences in the assessment of the intensity of nuisance based on surveys and studies carried out by the sensory team, the study area was divided into 10 areas (Fig. 5).

The area where odour nuisance, according to surveys, turned out to

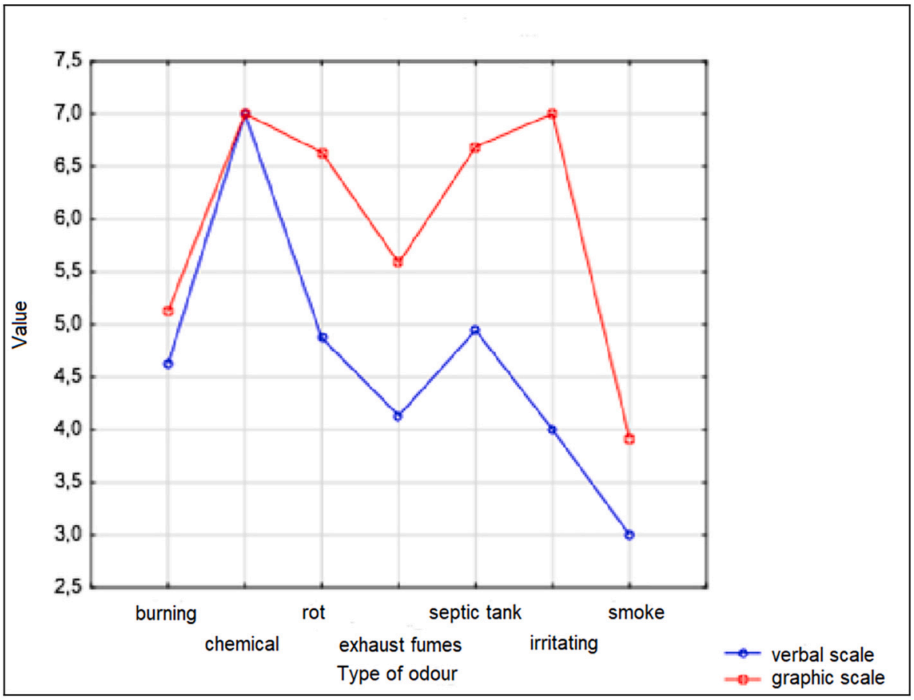

Fig. 3. Assessment of intensity of unpleasant odours and the strength of odours usually hovering in the study area.

be the largest is occupied by newly built housing estates.

3.2.2. Statistical analysis

The analysis and modeling of the gap related to the difference between the assessment made by experts and residents was made using the Dynamic Structural Equation Modeling (DSEM). In the first stage of the analysis, the dimensions of perceived odours were identified based on the homogeneity analysis using the multiple correspondence analysis (HOMALS algorithm). The results of the analysis indicate the existence of three main dimensions of odours (the fourth dimension has meaningless incremental contribution to cumulative VAF) (Fig. 6.).

All of significant regression parameters are negative, so it may be concluded that the higher hedonic quality of odour, air temperature, nuisance intensity of septic tank, exhaust and smoke dimensions of odour, the lower gap in assessment of odour intensity is. The R^2 of the model is 0.473. The tolerance, partial and semi-partial correlations of independent variables are displayed in Table 4. We can conclude that the assumption of the nonlinearity of independent variables is sustained.

Because of the spatial-temporal structure of data, the final analysis of variables involved dynamic structural equation modeling (DSEM). The DSEM may be represented in three types of models: 1/ general

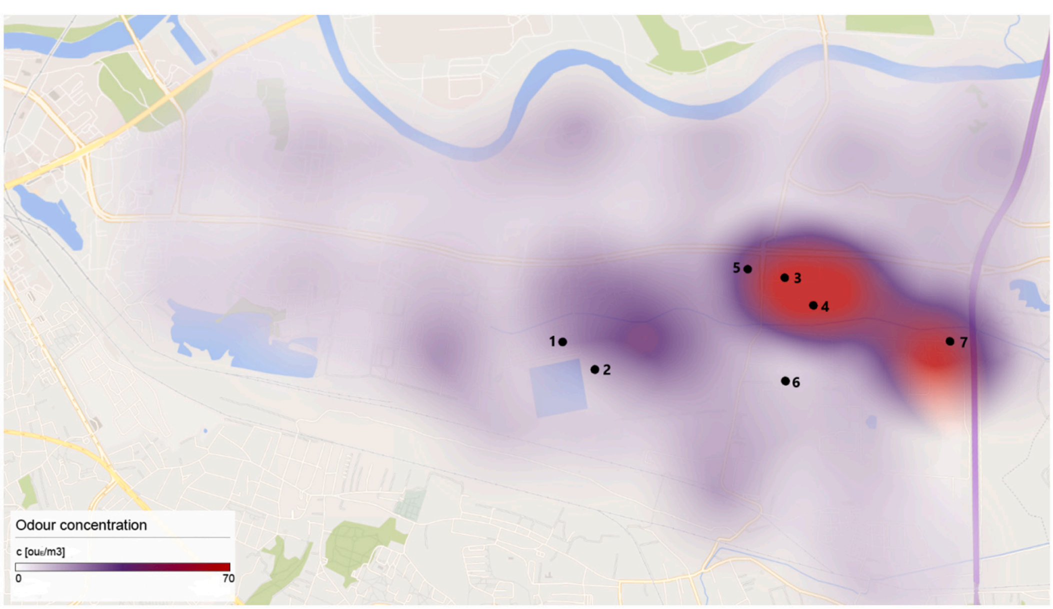

Fig. 4. Graphic presentation of the average odour concentration determined by means of the Nasal Ranger method expressed in terms of ou_E/m^3 in the period from September to November 2018

Table 2
Importance of dimensions are as follows (Variance Accounted For).

Variance explained	Dim1	Dim2	Dim3
Eigenvalues	2.0897	1.4643	1.2537
Variance accounted factor VAF	17.4143	12.2022	10.4473
Cumulative VAF	17.4143	29.6165	40.0638

Source: own research results.
The cumulative VAF shows that three dimensions account for 40% of the total inertia. After adding 4th dimension, no further substantial explanation of odours dimensions was obtained. So, three dimensions were maintained for further analysis purposes.

Table 3
Factor loadings of respective variables in three dimensions.

Type of odour	Dimension 1	Dimension 2	Dimension 3
Exhaust fumes	0.045	0.705	−0.147
Chemical	0.197	0.305	−0.454
Smell of burning	0.112	0.391	−0.587
Cesspool / sewage	0.650	−0.055	0.140
Garbage	0.498	0.191	−0.012
Sulfur	−0.122	0.652	0.329
Smoke	−0.221	0.487	0.518
Icky	0.610	0.046	0.303
Eggs	0.502	−0.121	−0.108
Carrion	0.588	0.028	0.224
Earthy	−0.057	−0.039	0.361

Source: own research results.
On the basis of factor loadings, three new variables determining the quantification of objects in three basic dimensions of odours were identified: 1 / excrements - decay, 2 / exhaust fumes - chemical, and 3 / smoky - earthy.
Those dimensions were used as variables accounting for the gap related to the difference between the odour assessment made by experts and inhabitants in the regression model and the DSEM.
In the second step, the multiple regression model for the overall sample was developed. The parameters of the models are depicted in Fig. 7.

random effect multilevel cross-classified DSEM nested both in time and respondent factors, 2/ two-level hierarchical DSEM with random effects on the respondent level only, and 3/ uni-level time series model for $N = 1$. We used the first model, in which the dependent variables were

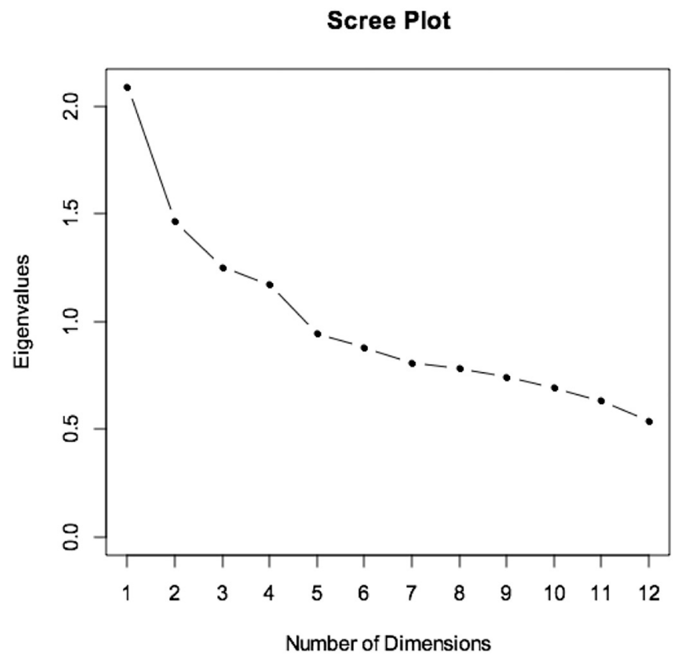

Fig. 6. Scree plot of eigenvalues in the multiple correspondence analysis.

decomposed on three components: 1/ error term, 2/ time-specific component and 3/ point-specific component (Asparouhov et al., 2018a; Asparouhov et al., 2018b; Asparouhov and Muthén, 2020):

$$Y_{it} = Y_{1,it} + Y_{2,i} + Y_{3,t} \quad (1)$$

where:

Y_{it} = value of dependent variable of measurement i in time t,
$Y_{1,it}$ - residuals ($Y_{1,it}$ = Y_{it} - $Y_{2,i}$ - $Y_{3,t}$),
$Y_{2,i}$ - point-specific component,
$Y_{3,t}$ - time-specific component.

The generalized DSEM model has the form of a non-hierarchical multilevel model consisting of an between-level and within-level structural model.

The within level model takes into account the components of the

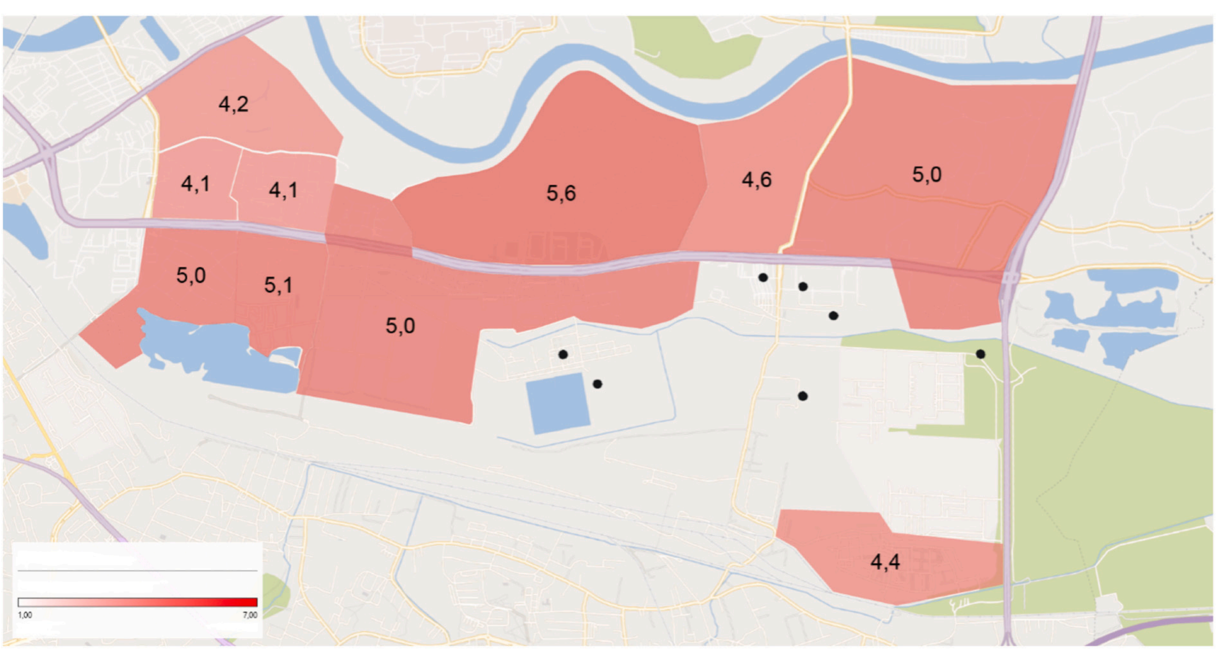

Fig. 5. Spatial analysis of the odour intensity (intensity areas).

Table 4
Evaluation of independent variables occurring in the multiple regression model of gap assessment.

Variable	Tolerance	Partial correlation	Semi-partial correlation
Air temp.	0.440	−0.213	−0.159
Relative humidity	0.460	0.023	−0.017
Atmospheric pressure	0.383	−0.033	−0.024
Wind speed	0.293	−0.013	0.009
Hedonic quality of odour	0.498	0.191	−0.012
Odour concentration	0.704	−0.231	−0.172
Excrements / decay	0.555	−0.191	−0.141
Exhaust fumes / chemical (or sulfur)	0.890	−0.237	−0.177
Smoky / earthy	0.973	−0.108	−0.079

Source: own research results.

time series in the form of an structural model:

$$\boldsymbol{Y}_{1,it} = \boldsymbol{a}_1 + \sum_{l=0}^{L} \boldsymbol{Q}_1 \boldsymbol{Y}_{1,i,t-1} + \sum_{l=0}^{L} \boldsymbol{\Gamma}_{1,l} \boldsymbol{X}_{1,i,t-1} + \boldsymbol{\varepsilon}_{1,it} \tag{2}$$

where:

a_1 - intercept.

$Y_{1,it}$ - values of deviations of dependent variables for point *i* and time *t*.

$Y_{1,it-1}$ - values of deviations of dependent variables for point *i* and time *t-1*.

$X_{1,it-1}$ - values of covariantes for point *i* and time *t-1*.

$\varepsilon_{1,it}$ - model residuals.

In the between-level structural model, the relationshps are represented by the following equations:

- structural model in cross-section of points (between-point level):

$$\boldsymbol{Y}_{2,i} = \boldsymbol{a}_2 + \boldsymbol{\Gamma}_2 \boldsymbol{X}_{2,i} + \boldsymbol{\zeta}_{2,i} \tag{3}$$

where:

$Y_{2,i}$ - point - specific and time-invariant dependent variable,

a_2 - intercept.

$X_{2,i}$ - point-specific and time-invariant covariate,

$\zeta_{2,i}$ - disturbances.

- structural model in the cross-section of time (between-time level):

$$\boldsymbol{Y}_{3,t} = \boldsymbol{a}_3 + \boldsymbol{\Gamma}_3 \boldsymbol{X}_{3,t} + \boldsymbol{\zeta}_{3,t} \tag{4}$$

where:

$Y_{3,t}$ - time - specific and point - invariant dependent variable,

a_3 - intercept.

$X_{3,t}$ - time - specific and point -invariant covariate,

$\zeta_{3,t}$ - disturbances.

Multilevel cross-classified dynamic structural equation models may also be estimated as models with random slope, random intercepts, random loadings and random residual variances across time or points.

The dynamic DSEM model is shown in Fig. 8. It consists of three submodels: within-level model, between time-level model and between-point level model.

* - parameters significant at $p < 0.05$.

Model within:

Dependent variable:

gap - centered gap between expert assessment made in points and periods of measurement, and the average assessment of residents living in point i. The assessment of odour intensity among residents was made on the basis of declarative opinions.

Independent variables:

Excrements - intensity of septic tank dimension of odour for point i and time t expressed in the standardized scale.

Exhaust fumes - intensity of exhaust dimension of odour for point i and time t expressed in the standardized scale.

Smoky - intensity of smoke dimension of odour for point i and time t expressed in the standardized scale.

Gap&1 - centered gap measurement immediately preceding a given measurement (delayed variable gap).

Hedonic quality of odour - intensity of odour for point i and time t.

C_{od} - olfactometry odour measurement for point i and time t.

Model between - time.

Dependent variable:

Gap - time-specific contribution of a gap that may be interpreted as the mean for time t,

Independent variables:

Excrements - mean of intensity of septic tank dimension of odour for time t expressed in the standardized scale.

Exhaust fumes - mean of intensity of exhaust dimension of odour for time t expressed in the standardized scale.

Smoky - mean of intensity of smoke dimension of odour for time t expressed in the standardized scale.

Airtemp - time specific air temperature.

Rel humidity- time-specific relative humidity.

Atmospheric pressure - time-specific atmospheric pressure.

Model between - point.

Dependent variable:

Gap - point-specific contribution of a gap that may be interpreted as the mean for point i.

Independent variables:

Excrements - mean of intensity of septic tank dimension of odour for point i expressed in the standardized scale.

Exhaust fumes - mean of intensity of exhaust dimension of odour for point i expressed in the standardized scale.

Smoky - mean of intensity of smoke dimension of odour for point i expressed in the standardized scale.

Average odour intensity - point-specific average of inhabitants ratings of odour.

Hedonic quality of odour – hedonic quality of odour for point i and time t.

C_{od} - odour concentration – c_{od} [ouE/m3] for point i and time t.

The model estimation was performed using the MCMC method (Bayesian estimation) within Mplus 8.2 software. The number of free parameters equaled 53, the Deviance Information Criteria = 222.189 and reached the lowest value for the compared different versions of the model (the model in Fig. 7 was finally selected for parameter interpretation purposes).

In the presented DSEM model, the dependent variable is the gap (gap) between the expert assessment carried out at various points and periods of measurement, and the assessment made by residents. In the internal model, the explanatory variables are the dimensions of odours (cesspool, exhaust fumes and smoke), the value of the gap in the preceding period (gap & 1), assessment of odour nuisance (burden) and c_{od}.

The within model presents the relationship of within-point variability of gap assessment over time and within-point covariates. The covariates are point-mean centered. The results show that all the parameters (except for gap&1) are statistically significant within person level. The within-point deviations of the gap is regressed on themselves (gap&1). The insignificant autoregressive parameter ($r = -0.018$) indicates no inertia or carryover of the gap effect (the closer to zero this parameter is, the shorter it takes a point to return to the equilibrium). The relationship between odour dimensions and the gap is negative. The higher intensity of odour, the lower gap deviations between experts and inhabitants are. In the case of septic tank odour, the strongest negative relationship ($r = -0.257$) is observed, so it means that septic tank odour has the strongest impact on concordance between experts and inhabitants. Hedonic quality of odour Hedonic quality of odour has also the strong and negative relationship with the gap in within-level model. The higher hedonic quality of hedonic quality of odour, the lower gap ($r = -0.662$) is. C_{od} (odour concentration) has only a slight

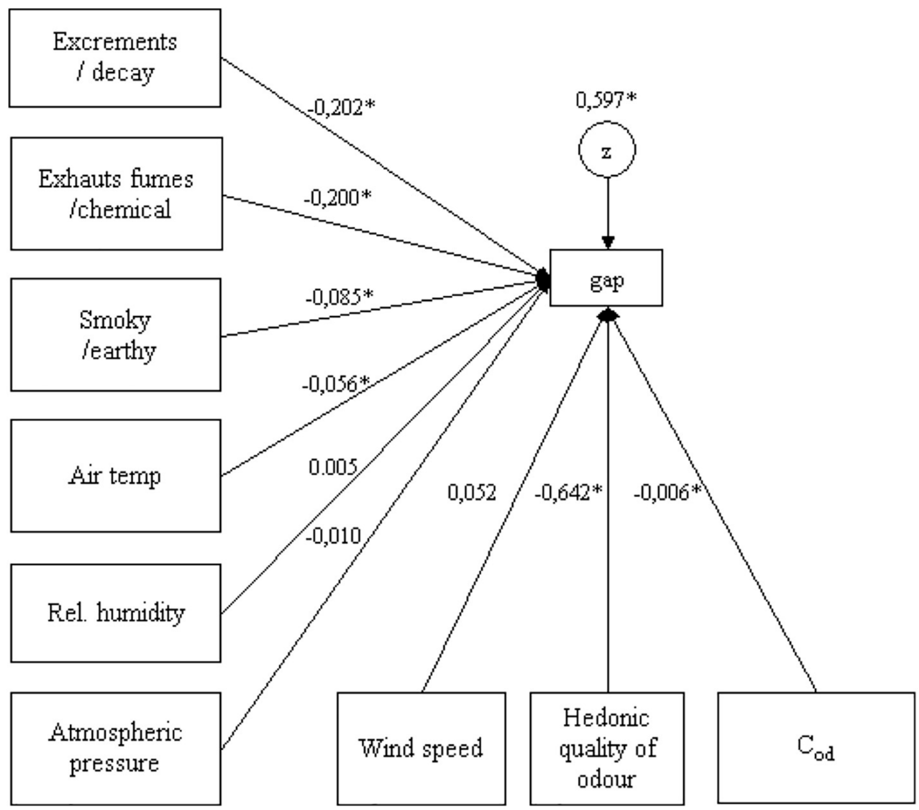

Fig. 7. Multiple regression model of gap assessment.

negative relation with gap ($r = -0.005$). The disturbance term (z = 0.406) represents the system noise or dynamic error.

In the between-level model, in addition to odour dimensions, there are time-invariant variables, such as air temperature, relative humidity and air pressure.

The between-time model expresses the relationship between odour dimensions and time-invariant covariates overtime (measurement occasions). All parameters are statistically insignificant. It may be concluded that time-invariant factors and odour dimensions do not account for the gap across measurement occasions. The insignificance of the relationships may be explained by the relatively short and season-specific research time (summer period).

The between-point model shows the relationship between odour dimensions, odour intensity (Hedonic quality of odour, c_{od}) and point-invariant covariate (srank). The significant and positive relationship between smoke dimension of odour ($r = 0.281$), average rank of inhabitants ($r = 1.062$) and gap is observed. On the other hand, there is the negative relation between exhaust dimension of odour ($r = -0.533$), hedonic quality of odour ($r = -0.634$) and the gap across points.

4. Discussion

To summarize, firstly, it should be noticed that there is the discrepancy (Simpson paradox) between the within-level and between-point level parameters for septic tank and smoke dimensions (negative

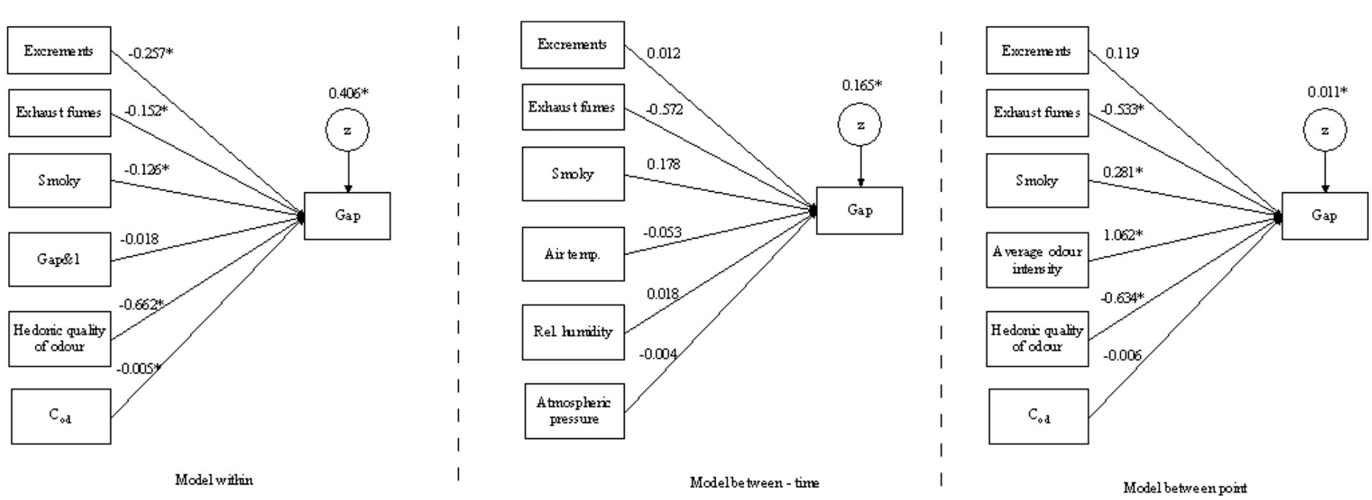

Fig. 8. DSEM model of gap assessment.
(Source: own research results)

on within- and positive at the between-point level) and consistency in the shape of the relation for exhaust dimension (negative on within- and negative at the between-point level). Secondly, the effect of odour intensity on the gap is noticeable across the point section rather than the time section, so spatial diversity has a stronger impact on the perceived gap as compared to the temporal one. Thirdly, in the within-level model, septic tank odour has a relatively stronger impact on the gap perception and exhaust than the dominant influence has at the between-point level whereas hedonic quality of odour has approximately the same influence at both within - and between levels.

Public opinion plays a decisive role in assessing the degree of irritation caused by unpleasant odours (Bertoni et al., 1993). When conducting surveys, it should be remembered that the odour nuisance is not assessed by residents only by means of sensory stimuli alone (VDI, 1997). Apart from the smell, such assessment, especially when it comes to perception of irritation, may be affected by other non-olfactory factors (La et al., 2014; Brandt et al., 2011), such as anxiety, distraction, personal comfort or visual cues (Belgiorno et al., 2013), attitude (Dalton et al., 1997), noise (Torres et al., 2010), or weather conditions (Gostelow et al., 2005). As a result of the survey, it was found that the average intensity depending on the area was kept within the range of 4.1 to 5.6 (on a scale of 1–7). At the same time, quite large discrepancies in the ratings were observed. In turn, for the sensory team, the scores ranged from 2.5 to 2.9 - so they were definitely lower. Therefore, it should be stated that there is no agreement between the intensity assessment determined by the residents and the expert team. The compared determinations show large discrepancies in the intensity assessment. These results are consistent with the research (Sucker et al., 2008), where residents rated industrial odours as more intense and unpleasant than experts did. It should be remembered, however, as Sucker also points out in his research that, when comparing the results of citizen surveys and expert team designations, it should be borne in mind that the experts' assessments were based on a direct sensation associated with the stimulus, and the opinions of the respondents were based on a flashback. Although it is costly to use an expert team, the results obtained seem more consistent. The expert team is a representative sample of the human population and is made of people with average but proven and repeatable sensory sensitivity. Sensory tests prove to be a good tool in examining residents' complaints about unpleasant odours. They also help, as shown in Figs. 3–4, to detect potential industrial facilities that may be sources of odours.

Higher intensities of odour nuisance that were indicated in surveys may be caused by the fact that repeated exposure to the smell may lead to high levels of irritation, and the residents' complaints themselves may come from people who are physiologically or psychologically sensitive to smell (Belgiorno et al., 2013). Although expert studies have shown that odour nuisance is at a lower level than indicated by surveys, the problem of unpleasant odours in this area exists. A very important issue is therefore a wide range of communication with the local community. The involvement of all the parties affected by this problem may in the future provide for not only the mitigation of the impact of the operations of potential odour generating facilities but may also increase tolerances in particular where those odours are relatively temporary.

5. Conclusions

The issues and methodology of the research proposed in the article constitute the subsequent stage in explaining and emphasizing the impact of odour nuisance on quality of life. It is also a step towards the objectification of this phenomenon through the use of diverse methods of measurement and comparison of results based on the same research object. The result of the analyses carried out by the expert team is a positive verification of the hypothesis about the possibility of objectifying the measurement of odours based on selected methods by indicating the compliance of results in terms of the occurrence of specific types of odours that negatively affect the standard of living in the study area. A valuable effect of the research is also the analysis of the discrepancy of measurement results and the determination of the so-called gaps, which allows to search for possible causes of the differences in the degree of nuisance of individual types of odours in the results obtained, caused by the specificity of the methods used. Therefore, it provides the basis for conducting further, more in-depth research on improvement of research methods and developing a coherent, comprehensive methodology for measuring odour nuisance, treating the presented results as a voice in further discussion. Due to the very significant impact of odours on quality of life, it seems necessary to develop research methods that would support decision making by both economic operators and public authorities, taking this factor into account in their operations.

The conclusion of the presented research is the fact that there is a certain discrepancy between the results obtained on the basis of the questionnaire-based assessment and the tests carried out by the expert team. The analysis of residents' surveys and comments obtained during the research shows that for a large group of residents, odour nuisance is strong. In the case of data obtained in the survey process, the average rating depending on the area ranged from 4.1 to 5.6 for the 7-point scale, while in the case of the expert team the assessment was below 3 points. Differences in perception of intensity and assessment of nuisance among respondents may result from many diverse variables. They may depend on the physiological and psychological state of the individual surveyed at the time of completing the survey, or the economic and social environment from which they originate. On the other hand, the use of the expert team allowed for obtaining results that were more consistent. It should be emphasized that obtaining precision and accuracy in tests using human senses is difficult but possibly because the expert team is calibrated by using appropriate selection procedures of candidates for assessors, and then undergoes training in accordance with the procedures set out in the international ISO standards, individual differences are somewhat reduced. As indicated in the research using the team, selected experts, by undergoing appropriate training in which directional odours selected for the scope of planned experiments were used, were able to recognize and define much more types of odours than was the case in the survey.

Conducting surveys reveals a number of important information about possible sources of emissions as well as the spatial diversity of their occurrence. Studies have shown how many dissatisfied people. However, the real scale of the problem seems to be smaller. In the light of the related literature, knowledge of the sensory analysis and the experience of other countries in the field of odour nuisance assessment and the impact of this nuisance on quality of life, it seems that there are no obstacles for the research conducted by independent experts to be a good verification of residents' complaints. They allow not only to determine the potential sources of the distribution of unpleasant odours but also to objectify the intensity assessment, which, without an affective (emotional) attitude towards the subject of the study, may be the answer to the question how important this problem is.

The authors are aware that odour nuisance is a sensitive area of research and may provide socially desirable responses (SDR effect), response set and faking bad effects due to socially important topics from the point of view of interactions between municipal policy and the residents' desires. However, the variety of measurement spatial points, interview timing and interviewers training concerning interview process and introducing warm-up questions enable to diminish potential bias in gap identification. Also, possible deviations and systematic bias up and down from the true score were, in our opinion, levelled out by the process of averaging the respondent ratings across the spatial points. It is very hard to assess the demographic differences and comparability between sample profiles of 1992 respondents and 4 highly trained panellist, that were trained according to the requirements of the sensory laboratory ISO's standards. The possible influence of panellist personal and social characteristics on the reliability and validity of odour measurements were removed after long term training and calibration process with a Nasal Ranger device.

The practical application of the article has been identified in several areas. The key aspects are the implications for policy makers in the preparation of spatial development plans and regional policy planning. Particular participation in this process will be related to social participation and the role of residents in making decisions about the shape of the region in which they live. Taking into account the voice of residents is the key to determining how to use public space and adapt the city's infrastructure. Controlling industrial emissions of volatile organic compounds is one of the most effective ways to reduce its pollution, which means that cleaner production is an important foundation for reducing odour pollution. Understanding the problem of odours in the environment (including odour origin, odour levels, management of odour sources, cleaner production, and reduction and detection methods) is very important for controlling odour pollution.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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