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Research article

METHODICAL APPROACHES TO SPATIAL IDENTIFICATION OF PROBABLE SOURCES OF OBNOXIOUS ODORS IN AMBIENT AIR BASED ON FUZZY LOGIC

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The article describes a task of searching for an unknown source of odor pollution. This task is classified as 'considerably uncertain', for which formal solution is proposed. The issue of obnoxious odor is relevant for many residential areas in large cities and industrial centers. Despite strict governmental control of emissions, including those from recycling facilities, undetermined pollution sources often become a reason for numerous people's complaints. Odor pollution is known to affect human health including the respiratory, cardiovascular and nervous systems; to reduce life quality and adaptation capacity. Industrial enterprises, treatment and recycling facilities are the most frequent sources of odor pollution. Complexity of air quality control is caused by subjectivity typical for odor perception and their multicomponent structure.

The suggested approach to searching for obnoxious odor sources is based on using statistical data about complaints made by people and up-to-date methods of the fuzzy set theory. Statistical data on people's complaints are subjective and emotional in their essence. In this method, an odor is represented as a linguistic variable that considers odor quality and intensity and weather and climatic conditions (wind speed and direction). The method assumes that an odor source is located in the direction opposite to the wind speed vector at the moment a complaint was registered. A possible location of an odor source was identified by superposing wind directions and considering impacts of a 'pollution plume', which had an area of dispersion of substances / a mixture of substances responsible for an odor. To perform more precise spatial searching for odor sources, the task was solved using fuzzy logic methods and a fuzzy conclusion considering a high level of uncertainty. The function of belonging was introduced to identify whether a point belonged to the multitude of probable locations of an odor source. Fuzzy model parameters were identified by using numeric experiments.

The suggested approach, which is based on analyzing statistical data about people's complaints, has been shown to not only conform to up-to-date trends in applied use of the fuzzy set theory but also to be able to solve the relevant task of identifying sources of odor pollution in ambient air. The approaches outlined in the article expand a sphere where the fuzzy set theory can be used introducing a new application trend for it, which is to determine reasons for differences between data obtained by laboratory control of ambient air quality and calculated dispersion of chemical emissions from stationary and mobile pollution sources.

Keywords: *fuzzy sets, odor, ambient air, population health, probable odor sources, complaints, life quality, mapping.*

The issue of obnoxious odor in ambient air is typical for many residential areas. It is especially acute in large cities and industrial areas with high population density, many industrial enterprises, heavy traffic, a lot of landfills for household waste storage and other signs of intense economic activity typical for highly urbanized territories.

Relevant public authorities perform their duties as regards controlling and managing the quality of the environment, supervising industrial emissions, regulating emissions and dis-

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charges, and organizing collection and storage of household and industrial waste. Despite all that, unaccounted pollution sources often occur spontaneously or deliberately in industrial areas; they create not only elevated levels of pollutants but also obnoxious odors. Obnoxious odors in residential areas result in growing numbers of complaints made by population. A lot of complaints are a clear signal for decision makers that an obnoxious odor should be eliminated; this often requires identification of its source.

Analysis of relevant publications with their focus on ambient air pollution with substances able to produce olfactory effects indicates that people who live in residential areas influenced by obnoxious odor sources more frequently suffer from respiratory diseases, cardiovascular diseases, diseases of the nervous system and mental disorders [1, 2]. People exposed to obnoxious odors have lower quality of life, suffer from emotional deviations and their adaptation capacity is reduced. Although estimations obtained by using surveys tend to be rather subjective, such studies still allow establishing elevated health risks, which are directly or indirectly caused by ambient air pollution with odorous substances [3].

Confectionary factories, bakeries, fish processing enterprises, tobacco and perfume productions as well as fuel-energy enterprises are most often mentioned as sources of obnoxious odors [4]. Some researchers are confident that wastewater treatment facilities are the major source of odor pollution [5].

Detection of odor pollution and associated health risks is a substantial argument for conducting relevant studies as regards hygienic regulation of levels of certain substances and their mixtures taking obnoxious odors into account [6].

Moreover, difficulty in developing measures aimed at eliminating obnoxious odors is largely associated with absence of any effective methods for control of odor pollution. A review by N.V. Syrchina with colleagues highlights the basic reasons that make quantitative measurements more difficult. They are associated with subjective perception of odors, complex multicomponent structure of pollutions, effects of synergy, masking and neutralization, which manifest themselves upon combined effects produced by various substances on human olfactory organs [7]. Population surveys, analysis of complaints as well as expert examinations involving volunteers' participation are common methods for investigating odor pollution [8].

It is noteworthy that social surveys and analysis of complaints reveal that people most frequently are unable to identify an odor and define it as obnoxious without any specifics. More precise identification is typical for odors, which correspond to specific chemicals such as hydrogen sulfide, ammonia, or natural gas. Complaints about such odors allow establishing what technological processes might be associated with their occurrence and specifying reasons and sources.

Intensity of an obnoxious odor is described by people with greater variety since they use both order categories ('mild', 'medium', or 'strong') and vivid emotional descriptions ('horrible', 'stinking', 'choking', 'impossible to breathe', etc.).

Effectiveness of measures aimed at eliminating obnoxious odors is largely determined by qualitative identification of reasons and sources of their occurrence. Searching for odor sources based on statistical data that reflect people's complaints with subjective assessment of an odor quality and intensity is a complex analytical task.

Search for obnoxious odor sources, which is based on statistical data containing subjective description of odors registered in people's complaints, areas of their localization and weather and climatic conditions, requires developing and implementing a methodology for identifying possible sources of obnoxious odors or areas where they may be located.

The aim of this study was to develop a method for identifying an area or areas where obnoxious odor sources may be located using statistical data about people's complaints as a basis.

Materials and methods. Due to the fact that statistical data about complaints are created by common people who are not experts in the field, objective quantitative features, estimation of odor quality and intensity are essentially uncertain and their descriptions are highly emotional. Given this uncertainty in descriptions and characteristics of an odor, a suggestion is to employ fuzzy logic and fuzzy inference algorithms as a scientific basis of a methodology for odor source identification. Within implementing fuzzy logic algorithms, an odor is represented as linguistic variables, which reflect its quality and intensity, as well as determined by weather and climatic indicators (wind speed and direction) at points where an odor and complaints about it are localized and registered.

When developing the method for identifying possible locations of obnoxious odor sources, we were guided by a conceptual assumption that such a source would be located in a direction opposite to the wind speed vector fixed at the moment when a complaint was registered. We identified areas where an obnoxious odor source might be located by generalizing a great number of complaints registered at different points within a residential area; the process was based on crossing the rays, which corresponded to wind directions. One should take into account that fundamental regularities in dispersion of substances in ambient air (G.I. Marchuk (1982)[1], M.E. Berlyand with colleagues (1985)[2]) describe an effect of dispersion in relation to the wind axis in a form of a so called 'pollution plume', which creates a blurred picture of spatial distribution of a pollutant concentration field.

Given that, when solving the inverse problem of pollution dispersion in ambient air, we assumed that an odor source might be located not at the wind axis but in a fuzzy area, which mirrors a 'pollution plume' in its shape.

This assumption implies substantial uncertainty as regards the problem of searching for a source location and requires using specific methods oriented at getting more precise areas and quantitative estimations. Accordingly, the problem of searching for an unknown odor source is essentially uncertain and cannot be solved within the formal logic paradigm. Yet, available statistical data about subjective estimations given to an odor by people allow employing the mathematical apparatus of fuzzy sets, fuzzy logic and fuzzy inference.

Theoretical algorithms of fuzzy inference suggested by E.N. Mamdani with colleagues[3] provided a methodological ground for the developed approach. They were based on linguistic variables being represented as fuzzy numbers and their subsequent aggregation.

According to conventional algorithms, use of fuzzy logic and fuzzy inference methods involves several stages including fuzzyfication, aggregation of conditions and conclusions, and defuzzyfication.

At the fuzzyfication stage, the system parameters are given as fuzzy sets. At the aggregation stage, the truth degree of conditions is determined per each rule of the fuzzy inference system. The defuzzyfication stage involves obtaining a quantitative value for each initial linguistic variable.

As regards the outlined problem, we used representing a coordinate system as fuzzy numbers as a basis for spatial modeling of an area where an odor source (a source of an odorous substance emission) might be located on the ground of people's complaints about obnoxious odors.

Since there was symmetry in pollution dispersion in ambient air, we employed polar coordinates with the center located at a point where a complaint was registered and the main axis directed oppositely in relation to

[1] Marchuk G.I. Matematicheskoe modelirovanie v probleme okruzhayushchei sredy [Mathematical modeling in ecological problems]. Moscow, Nauka Publ., 1982, 319 p. (in Russian).

[2] Berlyand M.E., Genikhovich E.L., Gracheva I.G., Onikul R.L., Chicherin S.S. Fizicheskie i metodologicheskie printsipy ustanovleniya predel'no dopustimykh vybrosov v atmosferu [Physical and methodological essentials of establishing maximum permissible emissions into ambient air]. *Trudy Glavnoi geofizicheskoi observatorii im. A.I. Voeikova*, 1985, no. 495, pp. 3 (in Russian).

[3] Mamdani E.H., Assilian S. An experiment in linguistic synthesis with a fuzzy logic controller. *Int. J. Man Mach. Stud.*, 1975, vol. 7, no. 1, pp. 1–13. DOI: 10.1016/S0020-7373(75)80002-2

the wind speed direction vector. That is, location of an odor source is determined by a distance from a point where a complaint was registered (*r*) and the angle of deviation from the main axis (φ). Figure 1 provides a scheme for location of a local polar coordinate system as applied to an arbitrary point where a complaint was registered.

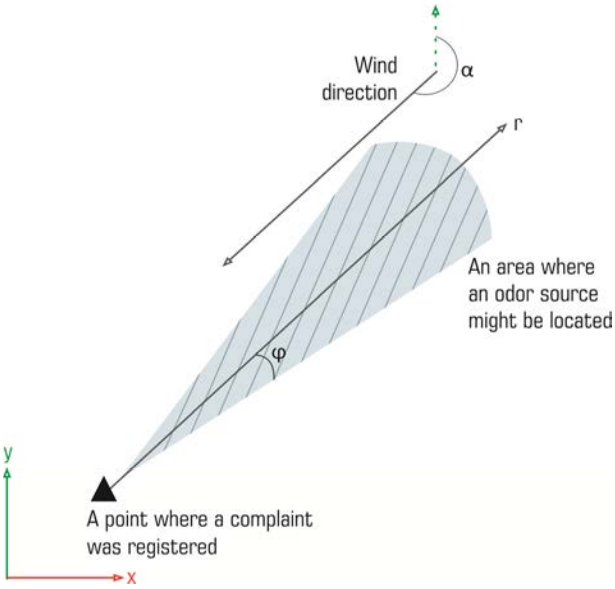

Figure 1. Scheme for location of a local polar coordinate system as applied to an arbitrary point where a complaint was registered

Following the logic of the outlined hypotheses and uncertainties, we assumed the local coordinates of an odor source to be the functions of the linguistic variable 'Odor Intensity' and the parameters of substance dispersion in ambient air depending on a wind speed.

At the aggregation stage, we set fuzzy coordinates for a possible odor source bound to each complaint and integrated belonging functions registered in the analyzed area. By doing this, we determined the belonging functions for a set of points where odor sources might be located. As a result of this integration procedure, we were able to create areas where an odor source was more likely to be located.

At the defuzzyfication stage, we analyzed spatial distribution of these obtained areas within a geoinformation system by differentiating them per various criteria and scales, using color visualization and identifying points of local peaks.

Results and discussion. A database with fuzzy inference rules for the problem of searching for a location of a possible odor source was created basing on inputting fuzzy coordinates in the space of regular mesh nodes. We employed pair fuzzy logic joins to establish a truth degree of points belonging to a set of possible locations. Defuzzyfication involved using the square center method.

The first stage in identification of obnoxious odor sources involved fuzzy data analysis by introducing a belonging function for a point to establish whether it belonged to a set of possible locations of an unknown odor source. Coordinates of a possible odor source location (*r*, φ) were given as fuzzy numbers for each compliant. Trapezoid shape was used as shape functions of curves for setting the belonging function for a distance to a possible odor source; triangle shape was used for the angle of deviation from the axis opposite to the wind direction.

Generally, the trapezoid shape of the belonging function is defined by four parameters (a_1, a_2, a_3, a_4), which determine coordinates of an odor source and are given as the following relationship:

$$\mu(x) = \begin{cases} 0, \ 0 \le r < a_1 \\ \left(\dfrac{x - a_1}{a_2 - a_1}\right), \ a_1 \le x < a_2 \\ 1, \ a_2 \le x < a_3 \\ \left(\dfrac{a_4 - x}{a_4 - a_3}\right), \ a_3 \le x < a_4 \\ 0, \ x \ge a_4 \end{cases}, \qquad (1)$$

where *x* is the coordinate of a possible odor source; $\mu(x)$ is the belonging function for the point with the *x* coordinate to establish whether it belongs to a set of points of a possible odor source location.

Figure 2 provides a graph for the trapezoid belonging function (1).

If the parameters a_2 and a_3 are equal, the trapezoid shape is transformed into the triangle one.

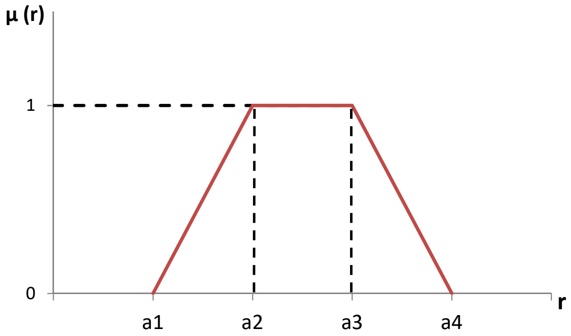

Figure 2. Graph for the trapezoid belonging function

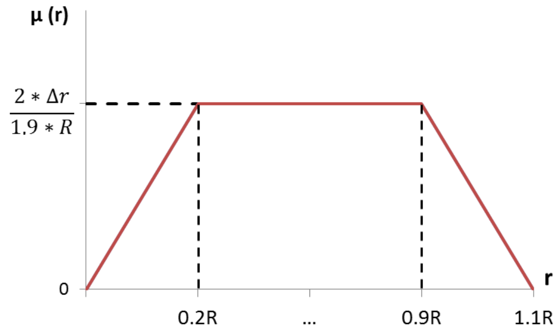

Figure 3. Graph showing the belonging function for the fuzzy coordinate: *r* (distance to an odor source)

Setting the belonging function in this way means that points, which are within the $a_2 \le r < a_3$ range, belong to a set, where an odor source is definitely located. Still, uncertainty conditions for the problem of searching for an odor source do not provide complete certainty for any point in an analyzed area. At the same time, if we accept the hypothesis that a complaint about an obnoxious odor necessarily means there is a single source of it located at a certain distance from a place where the complaint was registered, the conditions can be given as follows:

$$\int_0^{\infty}\mu(r)\,dr = 1 \text{ and } \int_{-\pi}^{+\pi}\mu(\varphi)\,d\varphi = 1 \qquad (2)$$

If the conditions (2) are met, it approximates the rules for setting a fuzzy coordinate to the probability theory axiomatics. Following the discrete character of calculating pollution dispersion over the regular mesh, we used averaging in a certain neighborhood Δr when setting the belonging function for each point. That is, the belonging function for the coordinate r with 20 % blurred bounds is given by the following relationship:

$$\mu\left(r \pm \frac{1}{2}\Delta r\right) =$$

$$= \begin{cases} \frac{2\cdot\Delta r}{(1.9\cdot R)}\left(\frac{r}{0.2\cdot R}\right), & 0 \le r < 0.2\cdot R \\ \frac{2\cdot\Delta r}{(1.9\cdot R)}, & 0{,}2\cdot R \le r < 0.9\cdot R \\ \frac{2\cdot\Delta r}{(1.9\cdot R)}\left(\frac{1.1\cdot R - r}{0.2\cdot R}\right), & 0.9\cdot R \le r < 1.1\cdot R \\ 0, & r \ge 1.1\cdot R \end{cases} \qquad (3)$$

where R is the parameter of a fuzzy number, which characterizes the maximum possible distance from a place where a complaint was registered to an unknown odor source and is determined by accomplishing the identification procedure; Δr is the neighborhood of a point where an odor source may be located, for which the belonging function is established.

The belonging function (3) can be graphically given as a trapezoid with its height depending on a scope of maximum odor spreading from a possible source and the size of the averaging area (Figure 3).

A sufficiently small value typical for a size of an analyzed area can be selected as a neighborhood value for a point where an odor source might be located (Δr). As this neighborhood value, it is recommended to use a regular mesh step, which is employed when calculating pollutant dispersion (for example, 100 meters).

Similar approaches were used to formalize the deviation angle of the odor source location axis from the wind direction axis; the fuzzy coordinate φ was given by the following relationship:

$$\mu\left(\varphi \pm \frac{1}{2}\Delta\varphi\right) = \begin{cases} 0, & -180 \le \varphi < -\varphi_0 \\ \frac{\Delta\varphi}{\varphi_0}\left(\frac{\varphi + \varphi_0}{\varphi_0}\right), & -\varphi_0 \le \varphi < 0 \\ \frac{\Delta\varphi}{\varphi_0}\left(\frac{\varphi_0 - \varphi}{\varphi_0}\right), & 0 \le \varphi < \alpha \\ 0, & \varphi_0 \le \varphi < 180 \end{cases}, \qquad (4)$$

where φ_0 is the parameter of a fuzzy number, which characterizes the maximum deviation angle of the odor source location axis from the wind direction axis and is determined by the identification procedure; $\Delta\varphi$ is the angle of deviation from the main axis, which determines the neighborhood of a point where an odor source might be located, for which the belonging function is set.

Figure 4 provides a graph to show the belonging function (4).

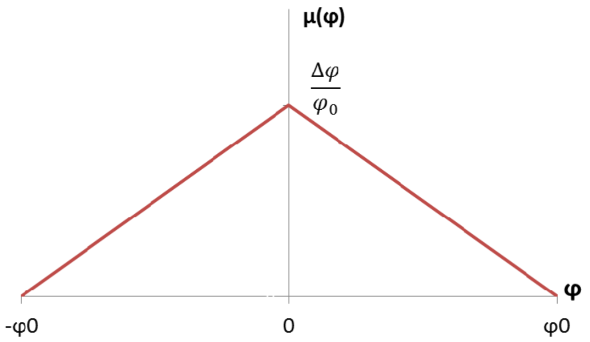

Figure 4. Graph showing the belonging function for the fuzzy coordinate: φ (the deviation angle of the odor source location axis from the wind direction axis)

The value of 1 degree was used as a value of the angle of deviation from the main axis, which determines the neighborhood of a point where an odor source might be located, for which the belonging function is set.

By setting the belonging function for each fuzzy coordinate of an odor source location relative to a point where a complaint was registered, it is possible to estimate all points within an analyzed area per their belonging to a set of points of a possible odor source location using the formula (5):

$$\mu(r,\varphi)=\mu\left(r\pm\frac{1}{2}\Delta r\right)\mu\left(\varphi\pm\frac{1}{2}\Delta\varphi\right) \quad (5)$$

At the aggregation stage, the fuzzy inference algorithm was employed to join fuzzy sets of points where odor source might be located, which were obtained for all registered complaints. To do that, prior to accomplishing the integration procedure, all results obtained by calculating the belonging functions were converted from a local polar coordinate system into the unified Cartesian coordinate system, which is conventionally used when calculating pollutant dispersion:

$$x = x_i + r\cdot\cos(\alpha_i + 180 + \varphi) \quad (6)$$

$$y = y_i + r\cdot\sin(\alpha_i + 180 + \varphi), \quad (7)$$

where x_i, y_i are the coordinates of a place where the *i*-th complaint was registered within the Cartesian coordinate system;

α_i is the wind direction angle within the Cartesian coordinate system.

Due to similar axiomatics in setting the belonging function for fuzzy coordinates and the probability density function, the rule for summating probability for joint events was employed for the integration procedure [9]:

$$\mu_{sum}(x,y) = 1-\prod_i (1-\mu_i(x,y)), \quad (8)$$

where $\mu_i(x,y)$ is the belonging function for the point with the coordinates (*x*, *y*), calculated for the *i*-th complaint;

$\mu_{sum}(x,y)$ is the belonging function for the point with the coordinates (*x*, *y*), calculated for all complaints.

The parameters *R* and φ_0 of a fuzzy model that describes an odor source location (3)–(5) were identified basing on numeric experiments that involved calculating dispersion of a typical odorous chemical, namely, hydrogen sulfide. Numeric experiments were accomplished using the software package Unified Program for Calculating Ambient Air Pollution (UPRZA Ekolog) 4.70.

When accomplishing calculations, we used a variable height of an odor source, mass flow rate of an emitted chemical (grams per sec) and wind speed. Mass emission of a pollutant was selected according to the requirements for establishing pollutant concentrations, which corresponded to the maximum odor intensity or 10 MPL[4] at a distance of up

[4] GOST R 58578-2019. Regulations for establishing environmental standards for odour and performing control of odour emissions, approved and enacted by the Order of the Federal Agency for Technical Regulation and Metrology dated October 8, 2019 No. 889-st. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200168570 (November 05, 2024) (in Russian).

to 5 km away from an odor source. This requirement is caused by the necessity to consider odor intensity. The linguistic variable Odor Intensity was used as a marker of ambient air pollution with an odorous substance and determined a probable level of a chemical at a point where a complaint was registered.

An actual term-set for the linguistic variable Odor Intensity, which is based on generalizing all possible subjective definitions in people's complaints, can consist of many values, which can be combined into a limited set of classes without any substantial information losses. To test the method for obnoxious odor identification, we used a score for identifying odor intensity as a term-set (determined per the 5-score scale conventional for hygienic research). This score was obtained by interviewing experts.

This term-set for the linguistic variable Odor Intensity was interpreted in conformity with the GOST R 58578-2019 Rules for Establishing Safe Standards and Control over Emissions into Ambient Air[5], which was used as a basis for comparing scores with actual levels of ambient air pollution with odorous substances.

In accordance with calculations of dispersion for odor source heights being 20–40 meters (this corresponded to an average height of odor sources in the analyzed area), no substantial differences were established in occurring ground-level concentrations of emitted chemicals. An organized odor source (a chimney) 20 meters high was selected as a model odor source. Figure 5 shows the results obtained by calculating dispersion of gaseous hydrogen sulfide from a typical source for the wind speed of 0.5, 1, 2 and 6 m/sec.

Obviously, when a wind speed grows, a 'pollution plume' becomes longer and simultaneously narrower. The calculated peak in concentrations occurs under a stronger wind and closer to the source. Calculations of dispersion revealed that levels at the limit of odor detection (1 MPL) could occur at a significant distance from the source (between 4 and 20 kilometers).

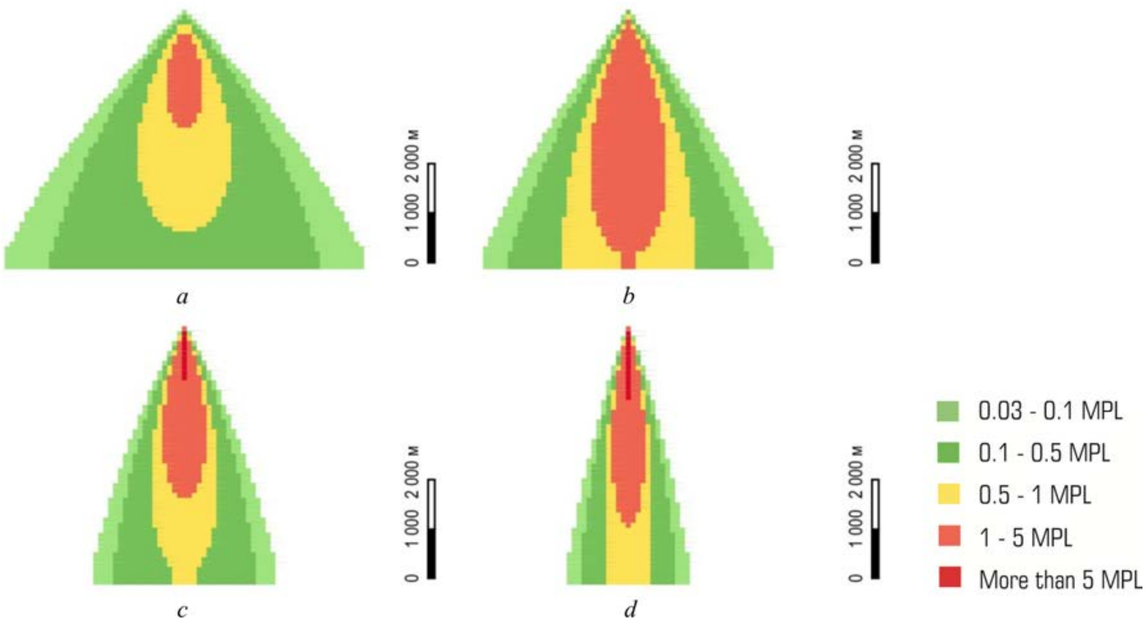

Figure 5. The results obtained by calculating dispersion of a gaseous hydrogen sulfide form a typical source for the wind speed of: a) 0.5 m/sec, b) 1 m/sec, c) 2 m/sec, d) 6 m/sec

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[5] GOST R 58578-2019. Regulations for establishing environmental standards for odour and performing control of odour emissions, approved and enacted by the Order of the Federal Agency for Technical Regulation and Metrology dated October 8, 2019 No. 889-st. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200168570 (November 05, 2024) (in Russian).

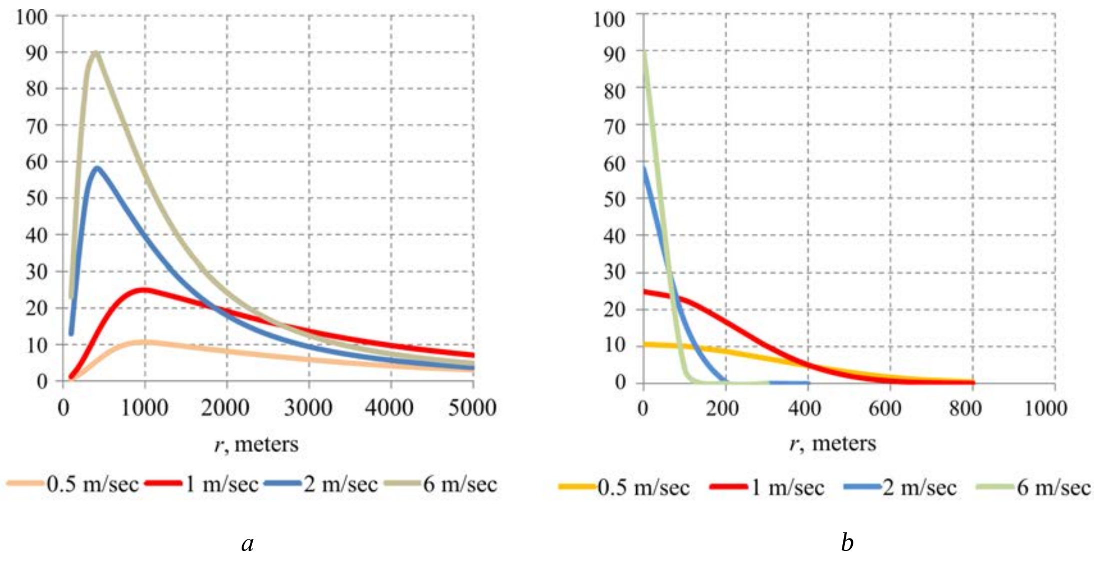

Figure 6. Graphs showing changes in pollution levels along the wind direction axis (a) and in the crosswise direction (b) from a typical emission source for various wind speeds

Table 1

Distribution of the parameter R per odor intensity and wind speeds for a typical emission source, meters

Odor intensity, scores	Wind speed, m/sec			
	0.5	1	2	6
1	15,868	18,579	11,058	11,129
2	10742	13452	8362	8590
3	8534	11244	7201	7496
4	3408	6117	4504	4957
5	1201	3909	3343	3863

Table 2

Distribution of the parameter φ_0 per odor intensity and wind speeds for a typical emission source, degrees

Odor intensity, scores	Wind speed, m/sec			
	0.5	1	2	6
1	43	36	35	26
2	38	32	27	25
3	34	30	26	24
4	22	22	23	14
5	6	17	19	13

The calculation results made it possible to formalize a relationship for intensity of pollutions at various distances form a source. Figure 6 provides graphs that show projections of pollution levels along the wind direction axis and in the crosswise direction.

An accomplished series of computations allowed obtaining tentative estimations of the parameters R and φ_0 for various wind speeds and odor intensity (Tables 1 and 2).

In accordance with the obtained estimations of the parameters R and φ_0, fuzzy coordinates were set for a possible location of an odor source. They are graphically visualized for various wind speeds in Figures 7 and 8. When calculating the belonging functions per the relationships (3)–(5), the values $\Delta r = 100$ meters, $\Delta\varphi = 1$ degree were used as a neighborhood of a point where an odor source was located.

Essentially, the relationships (3)–(8) and Tables 2 and 3 determine a fuzzy model that enables searching for a place where an unknown odor source is located basing on people's complaints. The computation algorithm is built on consistent analysis of all registered complaints, which, ultimately, serve to obtain an integral estimation of the belonging function of all points within an analyzed area in accordance with the relationship (8). The defuzzyfication stage involves spatial interpretation of the belonging function of those points within the analyzed area, which correspond to regular mesh nodes together with their visualization and scaling on a topographical map using GIS instruments.

The model for determining an area where an odor source might be located was verified and tested. This involved calculating the

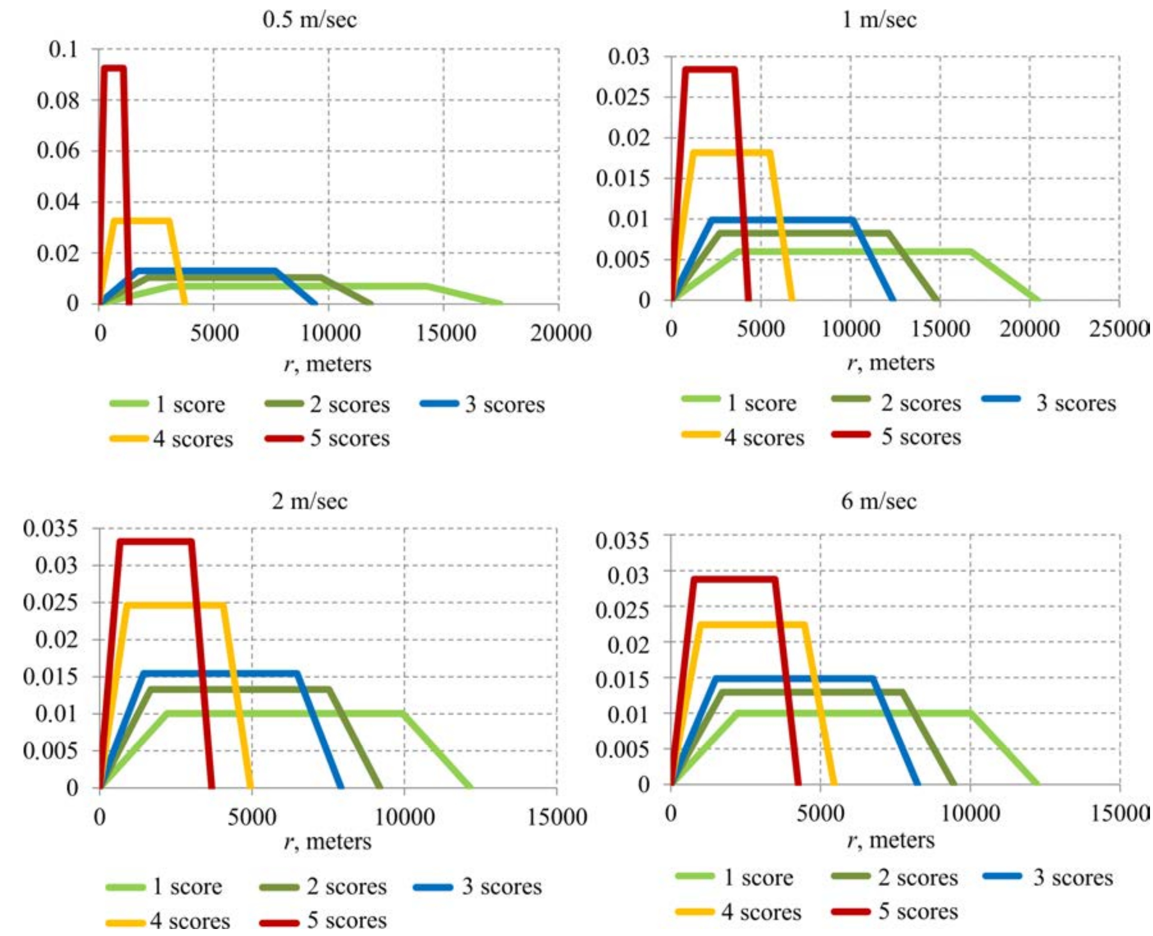

Figure 7. Graphic visualization of the fuzzy coordinate *R* for various wind speeds

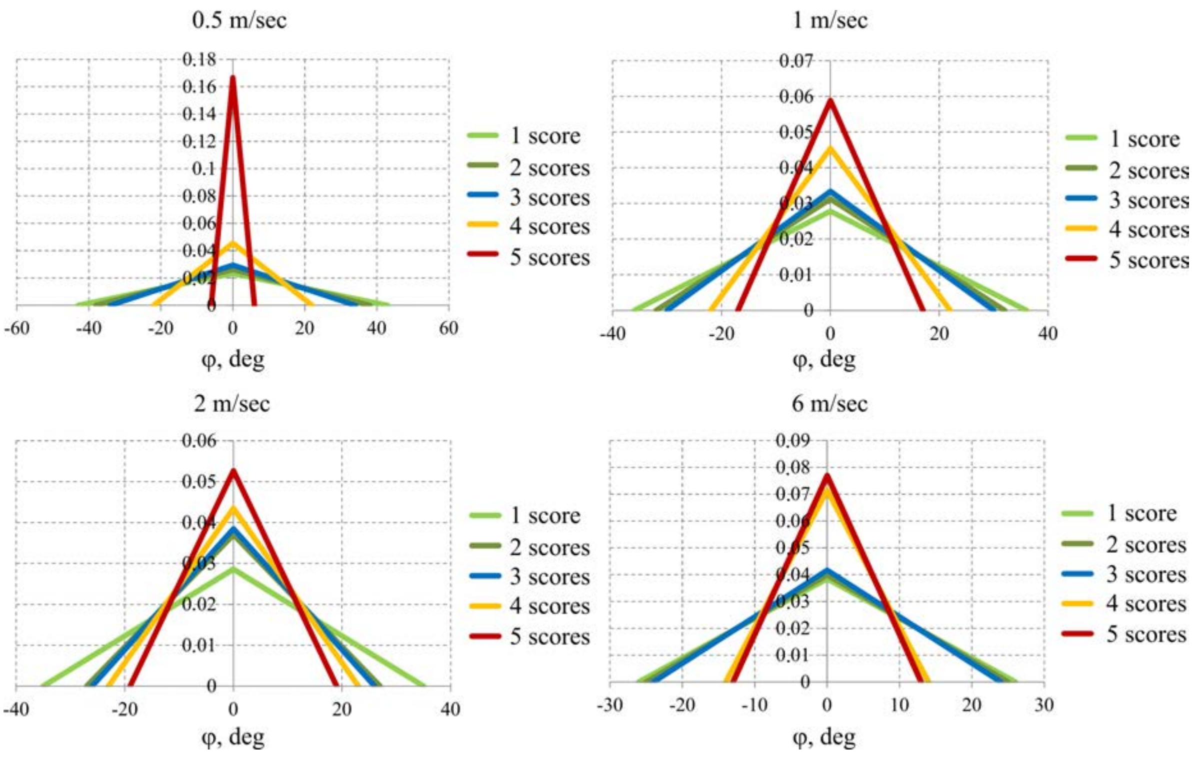

Figure 8. Graphic visualization of the fuzzy coordinate φ_0 for various wind speeds

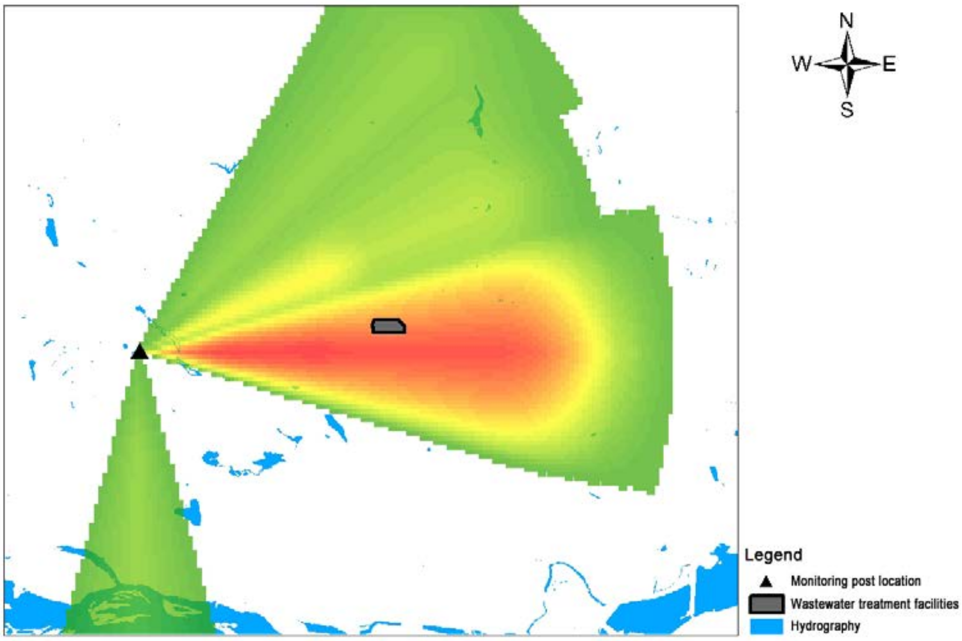

Figure 9. The results obtained by determining an area where an odor source was located in a test example

belonging function using the presented method based on laboratory control data about levels of hydrogen sulfide, which were collected at a monitoring post. The data were taken for a calendar year and an emission source was known. Figure 9 provides the results obtained by determining an area where an odor source was located in a test example.

In this example, the monitoring post simulated a point where a complaint was registered. The method approbation revealed that an obtained area contained a pollution source and the estimation was sufficiently reliable. This indicates that the suggested algorithm is an adequate and ready instrument for solving practical tasks. It is noteworthy that success in searching for unknown sources of obnoxious odors largely depends on a volume of initial data, which estimations of belonging are based on.

Given the fuzzy numbers that represent the linguistic variable Odor Intensity (Figures 7 and 8), the average assessment of the belonging function for a point (a regular mesh node) to a set of possible source locations is estimated by the order of values at the level of 10^{-3}. Consequently, in rough estimations, it is necessary to analyze approximately 1000 complaints to obtain reliable areas of possible source locations, which are characterized by the belonging function values close to 1. Maximum estimations per the majority of them should be set within the same area. Although such a condition can impose considerable limitations on successful identification of source locations, it simultaneously reduces probability of misinterpretation and obtaining estimation with low significance.

The developed methodology can be employed to identify a source (sources) of obnoxious odor, which reflects variable emotional estimations made by people as regards both its intensity and character.

Fuzzy logic and fuzzy inference ideas and classical algorithms were suggested by L. Zade (1965), E. Mamdani (1975), T. Takagi and M. Sugeno (1985) and others. They have been widely used not only in managing complex dynamic technical systems but also in practically every research sphere. Approaches based on fuzzy sets are actively employed to solve theoretical and applied problems in managing socioeconomic systems, ecology, healthcare, hygiene and other economic activities.

Practical use of such approaches in various scientific and technical spheres has shown fuzzy logic to be a powerful instrument for analyzing uncertain and inaccurate data, which include subjective and mostly qualitative estimations of phenomena and events. This ensures a more flexible and realistic approach to simulation of complex systems since it reflects human thinking and perception of the world.

Thus, research in risk management has established that use of fuzzy logic models ensures more adequate estimation of financial risks under marker uncertainties. Studies by S. Piramuthu (1999)[6] are a good example to illustrate it since he employed fuzzy logic models to estimate financial risks in unstable market conditions.

Use of the fuzzy set theory apparatus in Russian research works was analyzed by E.I. Muzyko who reported the highest interest in methods based on fuzzy logic in economic studies [10]. In such studies, authors investigate methods for estimating economic cost effectiveness for projects aimed at improving product quality [11], risks at various stages in a lifecycle [12], building an optimal monitoring system for ensuring food safety [13], as well as investment potential of industrial, construction and high-tech enterprises and the industrial complex as a whole. Fuzzy logic and fuzzy inference algorithms are actively used to analyze and predict features of economic and environmental safety of technogenic systems in the Russian Federation at the national, regional and municipal levels [14–20].

Analysis of publications with their focus on practical use of fuzzy logic in risk management as applied to medical, ecological and hygienic tasks has also shown that the approach is successfully used in managing complex sociodemographic processes. Such tasks are usually solved basing on development of experts systems, which imitate how decisions are made by experts under uncertainty [14–16]. As information and experts systems aimed at analyzing poorly defined data with spatial binding are being developed, algorithms for combining fuzzy models with geoinformatics and artificial intelligence methods are becoming especially significant. Such algorithms involve simulating logic of an expert responsible for data analysis and decision-making [23–26].

The suggested approach to searching for a source of obnoxious odor, which is based on analyzing people's complaints, is not only within the actual development trend in applied use of the fuzzy set theory but also allows solving an actual applied problem associated with identifying sources of ambient air pollution.

Essentially, the method makes it possible to solve the inverse problem of pollutant dispersion, which is an incorrectly formulated one and requires additional conditions and optimization criteria. The belonging function that determines whether a point belongs to a set of possible pollution source locations is used as an optimization criterion in the presented solution. The function maximum indicates the most probable location of such source.

Conclusion. In this study, we have shown that an essentially uncertain problem, such as searching for an unknown source of odor pollution, can have a formal solution. Accuracy of this solution largely depends on a volume and quality of statistical data, which describe odor intensity.

Use of the fuzzy logic methodology was largely determined by initial data represented by people's complaints; they were used as linguistic variables, which are very difficult to be analyzed using conventional methods for statistical analysis.

We have shown that the suggested approach to searching for a source of obnoxious odor, which is based on analyzing people's complaints, is not only within the actual development trend in applied use of the fuzzy set theory but also allows solving an actual applied problem associated with identifying sources of ambient air pollution.

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In addition, the approaches outlined in this study make it possible to establish promising trends in using the fuzzy set theory for identifying reasons for differences between data obtained by laboratory control of ambient air quality and calculated dispersion of chemical emissions from stationary and mobile pollution sources basing on statistical data collected at monitoring posts.

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