MODELING THE DISPERSION OF VEHICLE-RELATED EMISSIONS UNDER THE INFLUENCE OF WEATHER CONDITIONS AND DENSE URBAN AREA

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This paper presents the results of a study aimed at the development of mathematical methods for assessing air pollution based on fuzzy logic and neural network technologies. The object of the study is the dispersion of vehicle-related harmful substances, and the subject is the patterns of distributing the concentrations of these substances under the influence of urban area factors and weather conditions. The goal of the study is to develop a mathematical model for the dynamic calculation of the pollutant concentration cloud using computer modeling. The developed methods, as opposed to the existing ones, allow assessing the distribution of emission concentrations in real time and take into account the influence of building geometry factors, wind shadows, and weather conditions. The proposed approach allows detailing the spatial heterogeneity of air pollution in densely populated areas. The modeling results showed that under certain development parameters, the emission concentration in the leeward zone of buildings can more than double as compared to open urban environment areas. The analysis of the obtained data showed that the deviation of the results as compared to laboratory measurements does not exceed 20% in most of the studied urban areas, which confirms the high accuracy of the model. The results of the study have found their practical application as an algorithm integrated into the AIMS eco software which can be used for real-time environmental monitoring and the development of measures to reduce urban air pollution.

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Introduction

The developed urban infrastructure with high-rise buildings and heavy traffic is typical for most cities. Comfortable conditions for city residents entail negative consequences, including the deterioration of air quality. Vehicle exhaust gases (nitrogen oxides (NOx), volatile organic compounds (VOCs), carbon monoxide (CO), ammonia (NH3), sulfur dioxide (SO2), and primary particulate matter (PM), which are involved in the formation of harmful secondary pollutants such, as ozone and PM 2.5, in high concentrations (especially within signal-controlled intersections) negatively affect human health. Pollutants enter premises through doors, windows, and ventilation systems and are no less harmful to people indoors than outdoors [1]. Narrow streets, heavy traffic, and adverse weather conditions are the main reasons for the formation of high air concentrations of harmful substances [2, 3], [4]. Policy measures to reduce vehicle-related air pollution and associated controversies are discussed in [5]. The authors in [6] consider the implementation of measures to improve the dispersion of pollutants in urban canyons.

Urban environmental monitoring stations cannot accurately identify emission sources (households, industrial enterprises, or motor vehicles) and are applicable only to specific data collection locations.

The development and advancement of methods and mathematical models for assessing vehicle-related air pollution remains a fixed priority. Air pollution modeling includes various mathematical approaches describing cause-and-effect relationships between the characteristics of emission sources (traffic flow composition, speed, delay time) and factors influencing the dispersion of harmful emissions (urban area, weather conditions) [7-9]. The influence of the geometric details of building facades on the dispersion of harmful emissions in street canyons was studied in [10]. The paper established that building balconies affect dispersion, especially if they are located on the windward facade.

The dispersion of harmful emissions, air ventilation, and temperature changes in asymmetric urban structures were considered in [11]. Greenspace expansion, as a way to reduce air pollution, is used in modeling the air flow and the diffusion of harmful emissions in urban canyons [12].

The results of modeling the transfer of harmful substances are largely based on accurate input data: emissions inventory, meteorology, land surface parameters, and chemical mechanisms in the atmosphere [13].

There are several models of emissions from mobile sources. MOVES (Motor Vehicle Emissions Simulator) estimates harmful emissions based on vehicle operating modes. However, this simulator requires large computational costs and a lot of input data [14].

COPERT models vehicle emissions based on emission factors and is focused on the European Union [15].

HERMES and VEIN are open-source models based on computational languages (Python and R) and have transparent calculations with large data bulks [16, 17].

The Operational Street Pollution Model (OSPM) is fast and easy to use, but tends to underestimate real emissions in narrow street canyons [18].

Pollutant emissions depend on the amount of fuel used, the way the vehicle is driven (e.g. speed, acceleration, and vehicle load), the vehicle type, the fuel used, and the technology used to control emissions (e.g. catalytic converters). Therefore, the simplest way to estimate emissions is to use emission factors.

There is no universal model taking into account the specifics in time and space scales. The accuracy of the estimate depends on the accuracy of a huge amount of input data. The model should be simple and adaptive and present output information in the most convenient resolution.

There is a need to develop models that can assess the current state of air quality, take into account weather conditions, and provide information on emission sources to support management decisions.

CCTV cameras for monitoring traffic intensity and the amount of vehicle-related emissions on city highways and at intersections have been successfully used to collect data [19, 20]. The use of deep neural networks for recognizing moving objects on the road allows determining the vehicle type and speed and track the motion path. The obtained data are used to calculate the amount of emissions in real time [21, 22].

The developed AIMS eco (AIMS eco – Realtime Monitoring https://aims.susu.ru/demo) software suite implemented in several Russian cities monitors traffic flows and calculates pollutant emissions in real time; the data are updated at 20 minute-intervals. Emissions are calculated based on the regulatory documents of the Russian Federation (Order of the Ministry of Natural Resources and Ecology of the Russian Federation No. 804 dated November 27, 2019 “On approval of the Methodology for determining emissions of pollutants into the atmospheric air from mobile sources for conducting summary calculations of atmospheric air pollution”; GOST R 56162-2019 “Emissions of pollutants into the atmosphere”. Method for calculating the amount of emissions of pollutants into the atmosphere by flows of motor vehicles on highways of different categories.

This study presents a mathematical model for the dynamic calculation of a pollutant concentration cloud implemented in the Python programming language. The predictive probabilistic model of the influence of urban area building parameters is based on the fuzzy logic method. The modeling results serve as a good basis for understanding how the geometric parameters of urban area buildings affect the increase in pollutant concentrations when the emission source is located in wind shadows.

Conceptual model for calculating the pollutant concentration cloud taking into account the urban area

The main conclusion based on the analysis of regulatory documents on taking into account the urban area to calculate the dispersion of vehicle-related pollutant emissions [1] states that the presence of buildings near highways always increases the concentration of emissions. However, the influence of the housing system (urban area) is manifested only when the emission source falls within the possible formation of wind shadows from buildings. Leeward shadow and windward shadow zones are distinguished for the ground layer up to two meters high. Intermediate zones half the size of these two basic zones are distinguished for each of them.

The common calculation algorithm taking into account the influence of the housing system is expressed by the following formula: the maximum ground level concentration of pollutants $\hat{C}_m$ is determined as

$$\hat{C}_m = \hat{\eta}_m \cdot C_m \quad (1)$$

where $\hat{\eta}_m$ is the correction taking into account the influence of the housing system; C_m is the maximum ground level concentration of pollutants ignoring urban area.

Notably, calculations of the pollutant concentration cloud ignoring the urban area, which are also regulated by the relevant methods, were previously adapted for real-time monitoring upon receipt of information on traffic from stationary street surveillance cameras [2]. Ultimately, the complete mathematical monitoring model with the t_k periodicity at each point (x_m, y_m) of the emission concentration cloud $C^{tk}(x_m, y_m)$ for an urban intersection divided into N areal emission sources is represented by the general formula:

$$C^{tk}(x_m, y_m) = \sum_{i=1}^{N}\left(M_i^{tk} \cdot C_i'(x_m - \xi_i, y_m - \eta_i)\right) \quad (2)$$

where M_i^{tk} is the rate of vehicle-related emissions representing one areal source:

$$M_i^{tk} = \frac{1}{60} \cdot \Sigma_{j=1}^{K_{Pi}} M_{P_j} \cdot t_{P_i} + \frac{1}{3600} \cdot \Sigma_{l=1}^{K_{Vi}} r_{V_i} \cdot M_{L_l} \cdot V_l \cdot t_{V_l} \quad (3)$$

where t_{Pj} is the real idle time of the j-th vehicle during the increment time t_k ; t_{Vl} is the real time of movement of the l-th car with average speed V_l during the increment t_k over the area S_i.

$C_i'(x_m - \xi_i, y_m - \eta_i)$ are emissions at an arbitrary point of the intersection area (x_m, y_m) from one of N unit rate areal sources centered at the point (ζ_i, η_i).

$$C_i'(x_m - \xi_i, y_m - \eta_i) = C_m \cdot r\left(U/U_m\right) \cdot s_1\left(X/(p \cdot X_m)\right) \cdot s_2\left(Y/(p \cdot X_m)\right) \quad (4)$$

where the hazardous wind speed U_m and the reference value X_m, as well as a number of correction factors r, p, s_1, s_2 are precalculated taking into account the real wind speed U and wind direction.

This algorithm is a set of piecewise polynomial approximations for fast computer calculations. These approximations are based on the equations of atmospheric diffusion, as well as formulas for the Gaussian distribution of concentrations from a point emission source. The adapted algorithm is implemented in the AIMS eco software suite (AIMS eco – Realtime Monitoring), which monitors traffic flows and corresponding pollutant emissions in real time and presents data with a frequency of 20 minutes.

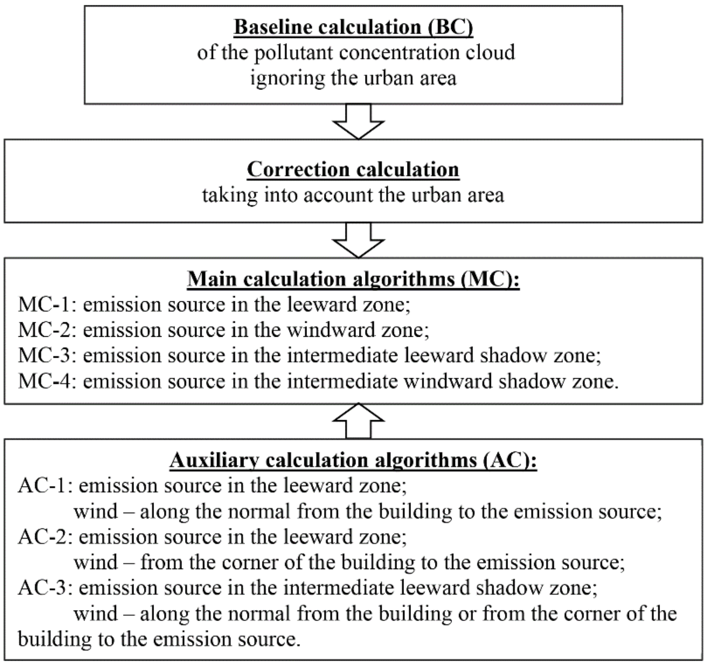
Figure 1 presents the conceptual model for correcting concentrations in the emission dispersion cloud calculated using formula (2), when introducing the correction $\hat{\eta}_m$, which takes into account the urban area.

The model contains three auxiliary algorithms necessary to operate each of the main algorithms. All the four main algorithms have a similar calculation structure based on the following provisions.

The ground level concentration of atmospheric emissions $C_{u,x,y}$ (ignoring urban area) at an arbitrary point (x,y) and the arbitrary values of wind direction and speed U is determined by the formula:

$$C_{u,x,y} = r\left(U/U_m\right) \cdot s_1\left(x/(p \cdot x_m)\right) \cdot s_2\left(y/(p \cdot x)\right) \cdot C_m = r \cdot \eta \cdot C_m \quad (5)$$

where $\eta = s_1 \cdot s_2$.



Baseline calculation (BC)
of the pollutant concentration cloud
ignoring the urban area

Correction calculation
taking into account the urban area

Main calculation algorithms (MC):
MC-1: emission source in the leeward zone;
MC-2: emission source in the windward zone;
MC-3: emission source in the intermediate leeward shadow zone;
MC-4: emission source in the intermediate windward shadow zone.

Auxiliary calculation algorithms (AC):
AC-1: emission source in the leeward zone;
wind – along the normal from the building to the emission source;
AC-2: emission source in the leeward zone;
wind – from the corner of the building to the emission source;
AC-3: emission source in the intermediate leeward shadow zone;
wind – along the normal from the building or from the corner of the building to the emission source.

Fig. 1. Conceptual model for calculating the emission concentration cloud taking into account the urban area

When taking into account the urban area, the ground level pollutant concentration is calculated similarly to formula (1) also at an arbitrary point (x,y) and the arbitrary values of the wind direction and speed U:

$$\hat{C}_{u,x,y} = r \cdot \hat{\eta} \cdot C_m \quad (6)$$

where only $\hat{\eta}$ is subject to correction.

The $\hat{\eta}$ coefficient calculation sequence is selected depending on whether the emission source base is in the leeward or windward shadow zone, or in the intermediate zone of these shadows. Therefore, let us consider in more detail the scope of one of the main algorithms, in particular, the first main algorithm MC-1: calculation of the correction taking into account the urban area, when the point emission source is in the leeward zone.

MC-1: first main calculation algorithm

When the emission source base is located in the leeward shadow zone, the $\hat{\eta}$ value at a point located at a distance x from the emission source along the flare axis and at a distance y from this axis is determined by the formula:

$$\hat{\eta} = (1 - \varsigma) \cdot s_1 \cdot s_2 + \varsigma \cdot s' \quad (7)$$

1) Calculation of the ζ coefficient

The ζ coefficient depending on the wind speed U and the positive acute angle γ between the wind direction and the normal to the leeward wall of the building is determined by the formulas from AC-2:

$$\begin{aligned} \varsigma &= 0.5 \cdot \left(\varsigma' + \varsigma''\right) \; when \;\; \gamma \le \varphi_k \\ \varsigma &= 0.5 \cdot \left(\varsigma' - \varsigma''\right) \; when \;\; \gamma > \varphi_k \end{aligned} \quad (8)$$

where ς' is calculated by the formula:

$$\varsigma' = 1 - \frac{1}{\left(1 + 2.9 \cdot 10^{-3} \cdot t_3 + 2.5 \cdot 10^{-5} \cdot t_3^2 + 9.2 \cdot 10^{-10} \cdot t_3^4\right)^2} \quad (9)$$

as the ζ' value calculated by the argument t_3 when φ_k is replaced with $(\varphi_k+\gamma)$; ζ'' is calculated similarly to ζ', but when φ_k is replaced with $|\varphi_k+\gamma|$.

In this case, the intermediate argument t_3 is calculated using the formula from AC-1:

$$\begin{aligned} & t_3 = \varphi_k \cdot \sqrt{U} \;\; when \;\; U \le 5 \;\; m/s \\ & t_3 = 2.24 \cdot \varphi_k \;\; when \;\; U > 5 \;\; m/s \end{aligned} \tag{10}$$

and the auxiliary angle φ_k depending on the building width/length ratio $t_2 = L_w/L_l$, is calculated using the formula:

$$\begin{aligned} & \varphi_k = 136.5 \cdot t_2^4 - 364 \cdot t_2^3 - 273 \cdot t_2^2 \;\; when \;\; t_2 \le 1 \\ & \varphi_k = 18 + \frac{281}{1+0.02 \cdot t_2^3} \;\; when \;\; t_2 > 1 \end{aligned} \tag{11}$$

2) Calculation of the s_1 and s_2 coefficients

These coefficients are calculated using the basic MA methodology ignoring the urban area.

3) Calculation of the s' coefficient

The *s*' coefficient is calculated by the formula:

$$\begin{aligned} & s' = \vartheta_1 \cdot \tilde{s}_2 \;\; when \;\; x \le x_b \\ & s' = \vartheta_1 \cdot \tilde{s}_2 \cdot \left(1 - s''\right) + s_1 \cdot s_2 \cdot s'' \, when \;\; x_b < x \le L' \\ & s' = s_1 \cdot s_2 \;\; when \;\; x > L' \end{aligned} \tag{12}$$

where all the auxiliary coefficients are also determined using auxiliary calculation methods. The corresponding formulas are omitted due to their cumbersomeness.

The main aspect in all calculation algorithms of the conceptual model is the replacement of the fundamental complex integral-differential and Gaussian dependencies with piecewise approximations using the simplest mathematical expressions. This significantly decreases the computational load in the software implementation of the considered algorithms.

Fuzzy logic-based model experiments

Any mathematical model reflects the actual situation with the probability that depends on a set of unpredictably changing factors, which are generally also interconnected. Therefore, it is advisable to conduct a model experiment in a probabilistic setting based on the Gaussian distributions of factors with random fluctuations.

The most suitable tool for the proposed experiment is an algorithm based on fuzzy inference, which allows avoiding bulky calculations. This algorithm was proposed by the English mathematician Ebrahim Mamdani in 1975 and found the maximum practical application in fuzzy modeling problems. According to the Mamdani algorithm, fuzzy inference is performed on a fuzzy knowledge base where the input and output variables are specified by fuzzy sets. The Mamdani algorithm and many other fuzzy inference algorithms (Larsen algorithm; Tsukamoto algorithm; Sugeno algorithm) have already been implemented in software products, in particular – fuzzyTECH, etc.

Let us consider probabilistic forecast constructions for the $\hat{\eta}$ correction, taking into account the influence of the urban area on the spread of pollutant emissions from traffic flows.

To obtain the minimax estimates of all parameters in the conceptual model, let us accept a number of assumptions without prejudice to the generality of the obtained results:

– th emission source is in the leeward shadow;

– he height of the emission source $H < 2$ m;

– the wind is directed along the normal to the urban building (angle $\gamma = 0$);

– this building side is designated L_w, and the adjacent side – L_l, wherein $L_w > L_l$;

– the building height is designated Hh and affects the size of the leeward shadow;

– the model is plotted for the maximum concentration point ($x = x_m$, $y = 0$), wherein $s_1 = s_2 = 1$.

Taking into account the adopted assumptions, the above main calculation algorithm MC-1 is reduced to the auxiliary algorithm AC-1 based on similar calculation dependencies:

$$\hat{\eta}_m = \left(1 - \varsigma_m\right) + \varsigma_m \cdot \left(r_3 \cdot \tilde{\eta} \cdot s\right) \tag{13}$$

The adopted assumptions allow selecting a specific calculation option in variational formulas (8)–(12), which ultimately allows obtaining a mathematical model of the correction in the change in the maximum emission concentration $\hat{\eta}_m$ in the following general form:

$$\hat{\eta}_m = f\left({}^{L_w}\!/_{L_l}, H_b\right) \tag{14}$$

where the building width/length ratio (L_w/L_l) and its height (H_h) are selected as input factors. Other intermediate parameters are calculated according to the following regulated ratios:

$$\begin{aligned} & \varsigma_m = 1 - \frac{1}{\left(1 + 2.9 \cdot 10^{-3} \cdot t_3 + 2.5 \cdot 10^{-5} \cdot t_3^2 + 9.2 \cdot 10^{-10} \cdot t_3^4\right)^2} \\ & t_3 = \phi_k \cdot \sqrt{\hat{U}_m} \;\; when \;\; \hat{U}_m \le 5 \;\; m/s \\ & \phi_k = 18 + \frac{281}{1 + 0.02 \cdot t_2^3} \;\; when \;\; t_2 > 1 \\ & t_2 = {}^{L_w}\!/_{L_l} \\ & r_3 = 0.67 \cdot \frac{\hat{U}_m}{U_m} + 1.67 \cdot \left(\frac{\hat{U}_m}{U_m}\right)^2 - 1.34 \cdot \left(\frac{\hat{U}_m}{U_m}\right)^3 \\ & when \;\; \frac{\hat{U}_m}{U_m} < 1 \frac{\hat{U}_m}{U_m} = \sqrt[3]{\frac{H}{H_b}} \;\; always < 1 \\ & \tilde{\eta} = 16 \;\; when \;\; H < H_b \\ & s = \frac{t_1 \cdot \left(t_1 - 1\right) + 1.47}{t_1 \cdot \left[1.62 \cdot t_1 \cdot \left(t_1 - 1\right) + 209\right]} + \frac{0.51 \cdot \left(t_1 - 4.92\right)^2}{t_1 \cdot \left(t_1 - 3.63\right)^2} + \frac{3.04}{t_1} \\ & when \;\; 8 < t_1 < 40 \\ & t_1 = \frac{\left(x_b - x\right) \cdot \sqrt{\tilde{\eta}}}{1.1 \cdot p_3 \cdot x_m} \\ & p_3 = 8.43 \cdot \left(1 - \frac{\hat{U}_m}{U_m}\right)^5 \end{aligned} \tag{15}$$

The minimax ranges of input factor variations are determined for the existing variants of the urban area along the main highways of Chelyabinsk, Russian Federation, for the building width/length ratio L_w/L_l from 2 to 20 and the building height H_h from 15m to 50m. In this case, the correction $\hat{\eta}_m$ varies in the range from 1 to 2.016.

The predictive probabilistic model of the influence of the parameters of urban area buildings (L_w/L_l; H_h) on the correction $\hat{\eta}_m$ is based on the fuzzy logic method and the fuzzyTECH computer program. Figure 2 shows the structural diagram of the model. At the stage of phasing the input factors, Gaussian membership functions were selected as splines, which maximally corresponds to problem statement in the stochastic version. The parameters of the Gaussian terms are determined according to the authors' expert estimates based on the analysis of the parameters of urban area buildings. Five Gaussian terms were selected in the membership function for the L_w/L_l factor, as the most variable parameter. Figure 2 also shows the distribution of values by terms. Three terms were selected for the H_h factor and five terms with a similar distribution of values were selected for the output value in the model.

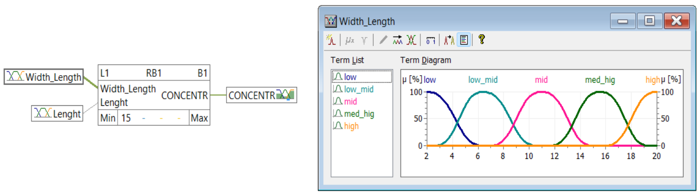
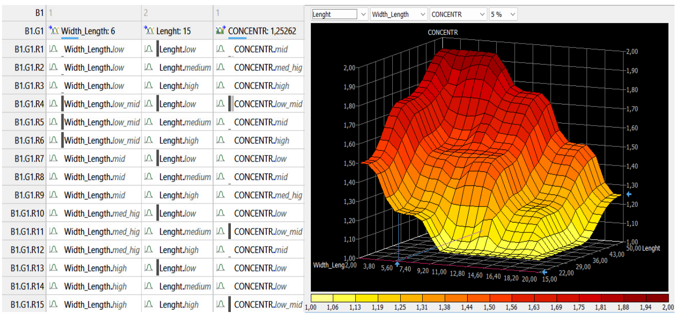


Fig. 2. Model diagram and terms for the Lw/Ll input factor

The logical fuzzy model for predicting the correction $\hat{\eta}_m$ was defined by the table of its relationships with the input factors using the Speadsheet rule editor block (Fig. 3).



B1	1	2	1
B1.G1	Width_Length: 6	Lenght: 15	CONCENTR: 1,25262
B1.G1.R1	Width_Length.*low*	Lenght.*low*	CONCENTR.*mid*
B1.G1.R2	Width_Length.*low*	Lenght.*medium*	CONCENTR.*med_hig*
B1.G1.R3	Width_Length.*low*	Lenght.*high*	CONCENTR.*high*
B1.G1.R4	Width_Length.*low_mid*	Lenght.*low*	CONCENTR.*low_mid*
B1.G1.R5	Width_Length.*low_mid*	Lenght.*medium*	CONCENTR.*mid*
B1.G1.R6	Width_Length.*low_mid*	Lenght.*high*	CONCENTR.*high*
B1.G1.R7	Width_Length.*mid*	Lenght.*low*	CONCENTR.*low*
B1.G1.R8	Width_Length.*mid*	Lenght.*medium*	CONCENTR.*mid*
B1.G1.R9	Width_Length.*mid*	Lenght.*high*	CONCENTR.*med_hig*
B1.G1.R10	Width_Length.*med_hig*	Lenght.*low*	CONCENTR.*low*
B1.G1.R11	Width_Length.*med_hig*	Lenght.*medium*	CONCENTR.*low_mid*
B1.G1.R12	Width_Length.*med_hig*	Lenght.*high*	CONCENTR.*mid*
B1.G1.R13	Width_Length.*high*	Lenght.*low*	CONCENTR.*low*
B1.G1.R14	Width_Length.*high*	Lenght.*medium*	CONCENTR.*low*
B1.G1.R15	Width_Length.*high*	Lenght.*high*	CONCENTR.*low_mid*

Fig. 3. Relationship table and forecast of the mutual influence of variables

Notably, the relationship table my contain inconsistent or even contradictory rules. To resolve such situations, fuzzy rules should be checked in both a static and a dynamic approach, although these issues are not considered herein.

The experimental studies of the model allow graphically representing the distribution field of the mutual influence of variables in the form of a volumetric surface. Figure 3 also shows such a field of mutual influence of input-output variables. The correction can be predicted numerically at the specific values of input variables. Thus, if the L_w/L_l ratio is 6 and the building height H_h is 15m, the emission concentration in the leeward shadow will be increased by 1.25 times.

The modeling results serve as a good basis for understanding the nature of the influence exerted by the geometric parameters of urban area buildings on the increase in pollutant concentrations when the emission source is located in wind shadows (in the considered example – in the leeward zone).

Development of a software suite for pollutant concentration monitoring

The above mathematical model for the dynamic calculation of the pollutant concentration cloud is implemented in the high-level Python programming language and integrated in the existing AIMS eco – Realtime Monitoring of vehicle-related pollutant emissions software system as an additional module. The AIMS Eco software suite monitors the concentration of vehicle-related pollutants in the urban environment, taking into account the influence of the urban area. It implements mathematical models for the dynamic calculation of the pollutant concentration cloud using fuzzy logic methods and computer modeling. The suite allows assessing the spatial heterogeneity of air pollution and adapting the calculations to real weather conditions.

AIMS Eco functionality includes:

- Automated collection of traffic flow data from CCTV cameras.
- Integration with city weather stations to take into account weather conditions.
- Real-time calculation of pollutant concentrations with a data update frequency of every 20 minutes.
- Use of machine learning algorithms to predict changes in pollution.
- Data visualization in an interactive city map taking into account the influence of the urban area.
- The software suite is developed in Python and implements optimized calculation algorithms reducing the computational load through the use of piecewise polynomial approximations. This allows promptly analyzing the air environment and taking measures to reduce pollution.

Verification of the model calculations of the pollutant emission concentration cloud

Various types of pollutants were measured instrumentally at four junctions of the urban road network in Chelyabinsk, Russian Federation. The measurements were aimed to assess the quality of the model calculations of the emission concentration dispersion implemented in the AIMS eco software suite, taking into account the urban area. The measurements were carried out using a mobile laboratory of Ecoanalytics Shared Use Center of South Ural State University.

The following verified measuring instruments were used:

- H-105, K-100, SV-320-A1 gas analyzers;
- NS chromatic analyzer;
- DustTRAK-8533 dust analyzer;
- IWS-4 integrated atmospheric parameter sensor;
- IVTM-7MS humidity and temperature meters.

The following weather conditions were recorded during the measurements:

- air temperature;
- relative humidity;
- atmospheric pressure;

- wind speed;
- wind direction;
- weather conditions.

The following pollutants were determined in the collected air samples:

- carbon monoxide CO;
- nitrogen oxide NO;
- nitrogen dioxide NO2;
- hydrocarbons CH;
- sulfur dioxide SO2;
- formaldehyde CH2O;
- benzopyrene C20H12;
- suspended particles PM2.5, PM10.

Figure 4 presents the verification results for carbon monoxide CO on weekdays at four intersections of the main urban highway in Chelyabinsk.

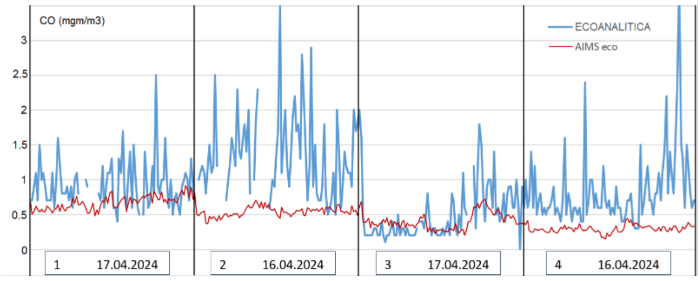


Fig. 4. Instrumental measurements and calculations for carbon monoxide CO

The calculated values of carbon monoxide emissions determined by the number of vehicles on highways are generally less than the instrumental measurements. This indicates the presence of a general background of emissions from industrial enterprises located within the city boundaries.

At the 1st and 3rd intersections, the average deviations of the calculated emission values from the instrumental measurements are within 20%. For the second and fourth intersections, the deviations are within 50%, which indicates a good level of calculation approximation to the actual situation taking into account the presence of background industrial emissions.

A similar situation is observed for other vehicle-related pollutant emissions, which generally confirms the correctness of the software implementation of the mathematical model for calculating vehicle-related emissions taking into account the urban area.

Conclusion

1. The authors developed a mathematical method for assessing the dispersion of harmful emissions in real time, taking into account the influence of the urban area and weather conditions on the pollutant concentration. Unlike the existing approaches, the proposed method allows for detailing the spatial distribution of emissions and adjusting calculations in view of the current weather conditions. The experiments showed high calculation accuracy. The deviation of the calculations from the laboratory measurements does not exceed 20%.

2. A new adaptive algorithm for modeling the dispersion of emissions has been proposed as a practical application of the research findings. Unlike the existing ones, it takes into account complex aerodynamic processes in the urban environment. The practical significance of the method lies in its applicability for operational environmental monitoring and the development of measures to reduce air pollution in metropolitan cities.

3. The use of the developed mathematical methods for assessing the dispersion of harmful emissions can significantly improve the accuracy of air pollution forecasts in the urban environment. Unlike traditional static models, the proposed methodology ensures the dynamic adaptation of calculations, which is essential in case of sudden changes in weather conditions and traffic flows. This opens up new opportunities for the more accurate planning of urban space and development of measures to reduce environmental loads. The use of the developed methodology in urban planning and air quality monitoring will minimize the impact of emissions on the environment and public health.

4. Further research prospects include the advancement of algorithms for taking into account microclimatic factors of the urban environment, the introduction of machine learning to improve the accuracy of pollution forecasting, and the integration of the methodology into environmental monitoring systems for prompt decision-making.

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МОДЕЛИРОВАНИЕ ПРОЦЕССА РАССЕИВАНИЯ ВЫБРОСОВ ВЕЩЕСТВ ОТ АВТОТРАНСПОРТНЫХ ПОТОКОВ ПОД ВЛИЯНИЕМ МЕТЕОУСЛОВИЙ И ПЛОТНОСТИ ГОРОДСКОЙ ЗАСТРОЙКИ

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Аннотация

В статье представлены результаты исследования, направленного на разработку математических методов оценки загрязнения воздуха, основанных на нечёткой логике и нейросетевых технологиях. Объектом исследования является процесс рассеивания вредных веществ, выбрасываемыми автотранспортными потоками, а предметом – закономерности распределения концентраций этих веществ под влиянием факторов городской застройки и метеорологических условий. Целью исследования является разработка математической модели динамического расчёта облака концентрации загрязняющих веществ при помощи компьютерного моделирования. Разработанные методы, в отличие от существующих, позволяют оценивать распределения концентраций выбросов вредных веществ в режиме реального времени и учитывают влияние факторов геометрии зданий, ветровых теней и метеорологических условий. Предложенный подход позволяет детализировать пространственную неоднородность загрязнения воздуха в условиях плотной застройки. Результаты моделирования показали, что при определенных параметрах застройки, концентрация выбросов в подветренной зоне зданий может увеличиваться более чем в два раза по сравнению с открытыми участками городской среды. Анализ полученных данных показал, что отклонение результатов в сравнении с лабораторными измерениями составляет не более 20% на большинстве исследованных участков города, что подтверждает высокую точность модели. Результаты исследования нашли своё практическое применение в качестве алгоритма, который интегрирован в программный комплекс "AIMS eco" и может быть использован для оперативного экологического мониторинга, разработки мер по снижению загрязнения воздуха в городах.

Ключевые слова: *транспортные потоки, выбросы загрязняющих веществ, концентрация выбросов, городская застройка; нейросетевая модель, программный комплекс, ветровые тени*

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