Methodology of motor transport air pollution monitoring of large city taking into account residential development type

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Abstract. A complex method of motor transport air pollution monitoring of a large city was developed, taking into account meteorological conditions and types of residential development, combining traditional computational methods, the results of field research, data obtained from the experiments on dispersion modeling of motor vehicle emissions under various conditions and mathematical modeling. The methodology allows for the operation of a monitoring system for a part of the city’s territory (within the given boundaries). It’s able to determine areas with negative ecological condition in need of management decisions to improve the urban environment; identify favorable areas where it is possible to ensure complete ecological safety when placing construction sites; predict changes in the atmospheric air quality in a changing residential development.

1. Introduction

An important source of air pollution, the importance of which as the pollution of the urban environment increases every year, is motor transport. With the increase in the intensity of motor traffic in cities, the most polluted areas moved from industrial zones to dense populated areas. In recent years in the cities around the world, there is a significant increase in the amount of vehicles. According to the “Avtostat” analytical center, as of January 1, 2018, the amount of vehicles in the Russian Federation reached 50.6 million units. Almost 84% of this number is accounted for by passenger cars, 8% of the total amount belongs to light commercial vehicles, over 7% are trucks, and about 1% is buses.

The Volgograd Region is among the 25 subjects of the Russian Federation with the largest number of passenger cars (about 660000). The share of vehicle emissions of pollutants into the atmosphere in the total amount of emissions in the region exceeds 60%, and in the city of Volgograd it reaches 70%.

There are about 280 components in the vehicles exhaust gases, many of which are toxic.

Existing systems of atmospheric air monitoring do not take into account the dynamics of urban conditions, such as changes in the of traffic, volumes and composition of industrial emissions, the emergence of new industries, changes in the relative location of pollution sources, the emergence or disappearance of areal pollution sources (poorly maintained areas), and seasonal wind dynamics.
When organizing monitoring systems, it is also advisable to take into account the inclusion of construction sites that require varying degrees of protection (kindergartens, residential areas, sports facilities, etc.) and features of dispersion of pollutants in the city in the context of existing planning decisions and changes in development of residential areas.

The multi-factorial impact on the urban environment, as well as the mentioned disadvantages of the existing atmospheric air monitoring systems, make it possible to consider the topic of the study as relevant.

2. Characteristics of vehicles as a source of air pollution. Models and methods of monitoring air pollution by motor transport

Distinctive characteristics of vehicles as a source of air pollution include constant increase in numbers of motor vehicles and, therefore, emissions amounts [1]; constant changes in the tracing and intensity of the city’s highways in a changing development; the penetration of cars into residential areas and recreation areas [2-4]; the release of pollutants in the human respiratory zone and difficulty dispersion in urban areas [5-10]; multi-component emissions (over 200 pollutants) [11].

Taking into account all the features of road transport as a source of pollution, a prerequisite for the development of measures to reduce its negative impact on the urban environment is the development and improvement of the monitoring system of atmospheric air, which should be carried out on a modern organizational and technological basis, with a combination of using representative field data modeling.

According to the analysis of a number of works [12–21, etc.], four main directions of development of the emissions and solid particles dispersion in the atmosphere of cities can be distinguished in:

- Using statistical propagation models based on the Gaussian distribution.
- Modeling of currents in street canyons by solving transport-diffusion equations.
- Physical modeling in wind tunnels.
- Building models based on an integrated approach: a comparative analysis of the results of field experiments, the results of mathematical and physical modeling.

Existing atmospheric dispersion models based on the use of an integrated approach, such as OSPM [19,20], CALINE-4 [21], etc., do not fully take into account the dispersion factor of pollutants inside the residential areas.

It’s decided to use a combination of calculation methods, results of field experiments and methods of physical and mathematical modeling, therefore allowing us to take into account this factor.

3. Modeling of air pollution by motor transport, taking into account the type of residential development

As a baseline for calculating the vehicle emissions to the atmosphere on existing highways, the results of our own field studies of the structure and intensity of motor traffic with the division by main groups of motor vehicles were obtained [8-10]. These field surveys do not require complex instrumental equipment, and this allows the performance of the surveys of any city highway with a given frequency, which is an important condition for regular updates and adjustment of information on motor vehicle emissions.

Based on a study of the city’s road network and the traffic condition, a list of highways with different traffic and intersections with high traffic loads was compiled. To determine the characteristics of motor traffic flows in selected sections of the road network vehicles moving in both directions were also taken into account.

The counting of the vehicles on the studied highways has been carried out for 20 minutes every hour. With high traffic intensity (more than 2-3 thousand cars per hour), the counting of vehicles was carried out simultaneously for the both opposite directions.

To identify the maximum traffic load, observations were conducted at peak hours. For most city streets, peak hours are in the morning and in the evening (from 7.00-8.00 to 10.00-11.00 and from 16.00-17.00 to 19.00-20.00).
Field surveys of the traffic structure and load were carried out 8-10 times at peak hours on each highway within 5-7 working days.

To determine air pollution by motor vehicle emissions a method described in GOST R 56162-2014 “Emissions of pollutants into the atmosphere. Method of calculating emissions from motor vehicles when conducting summary calculations for urban settlement” is used. [22] It allows us to calculate the amount of pollutant emissions into the atmosphere by traffic on highways of various categories.

The concentration of CO in the middle of the street is determined by the calculation method described in the GOST R 56162-2014.

To calculate the emissions dispersion from motor transport and the concentration of toxic substances at the different distances from the roadway, we used the Gaussian pollutants distribution in the atmosphere at low altitudes. [10].

The concentration of air pollutants such as carbon monoxide, hydrocarbons, nitrogen oxides, lead compounds by the roadway is determined by the formula:

\[
C = \frac{2q}{\sqrt{2\pi} \times \sigma \times \sin \phi}
\]

where

- \( C \) - the concentration of this type of pollutant in the air,
- \( q \) - the concentration of this type of pollutant in the middle of the road,
- \( \sigma \) - standard deviation of the Gaussian dispersion in the vertical direction,
- \( \phi \) - the angle between the wind and the road. At an angle of 90 to 30 degrees, the wind speed should be multiplied by the sine of the angle; at an angle of less than 30 degrees the coefficient is 0.5.

The existing methods for calculating the dispersion of motor vehicle emissions do not take into account the residential areas around the street, which is important for estimating and predicting air pollution in the city and for the monitoring networks planning. The study of the dispersion of vehicle emissions in urban areas in natural conditions is challenging. First, it is the difficulty of assessing the protective role of the elements of the buildings layout and residential development due to the randomness of the traffic flow; short duration of air sampling; changing meteorological factors; the complexity of simultaneous observations at many points and objects, etc. Thus, when studying the spread of motor vehicle emissions inside the residential areas, it is possible and necessary to use a modeling method that, by eliminating the above difficulties, creates conditions for a more accurate quantitative assessment of the studied phenomenon. To create models of vehicles emission dispersion in the study area, data from the experiments on vehicle emissions modeling under various urban development conditions, made by V.F. Sidorenko at the urban modeling stand in cooperation with the specialists of the Central Research Institute of Urban Planning, RAACS, NIISF RAACS, IISI has been used [8-10].

The data obtained from carbon monoxide dispersion modeling process turned out to be very close to the data obtained during the field experiments. This allowed us to use the obtained correlations to predict the processes of dispersion of pollutants and draw areas of pollution in any typical situations in the city.

According to the experimental data obtained at the dispersion modeling site the dispersion of pollution, the distribution of carbon monoxide concentrations inside the residential development areas is determined by the combinations of types of residential development. In the case of building construction, the concentration is calculated in the same way as in an open area, an elevated CO concentration is observed on a standing building, the concentration behind the building is reduced by 50-70% of the concentration in the open area. With closed planning decisions in the courtyard, the concentration of CO is increased by 20-30% compared with the expected for a conventional frontally located building.
The concentration of air pollution by carbon monoxide, depending on the residential type, is determined by formulas similar to the calculation without taking into account the residential development, but with the addition of the $L$ factor.

An analysis of the street condition of the experimental area was carried out for each type of residential development. All streets were categorized and aligned to a common basis. For convenience of calculations, four types (categories) of residential development were selected in accordance with Table 1.

The obtained correlations allow us to obtain data on the concentration of pollutants (carbon monoxide) at a set distance from highways of various categories, depending on the type of residential development.

**Table 1.** Coefficients for calculating air pollution from vehicle emissions, taking into account the type of residential development.

| Residential development type | Decrease (-) / Increase (+) in CO concentration, % | $L$ Factor |
|------------------------------|--------------------------------------------------|------------|
| Detached                     | 0                                                | 1          |
| At an angle                  | -10                                              | 0.9        |
| Frontal                      | -50-70                                           | 0.5-0.3    |
| Perimetric                   | 20-30                                            | 1.2-1.3    |

Using the developed methodology, the calculation of the pollutants dispersion of various types of residential development and weather conditions was carried out (Figures 1-2).

**Figure 1.** Microdistrict development with the east wind in the warm period of the year (2 m/s wind).

**Figure 2.** Quarterly development with the west wind in the warm season (wind 2 m/s).

4. Conclusion
The developed methodology for atmospheric air pollution monitoring of a large city by motor transport, taking into account meteorological conditions and the type of residential development, will allow: to provide a monitoring system for a portion of the city’s territory (within the specified boundaries and the required area); determine environmentally unfriendly areas in need of urgent management decisions to improve the urban environment; identify favorable areas where it is possible
to ensure complete environmental safety when placing construction sites; predict changes in the state of atmospheric air in a changing residential development.

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