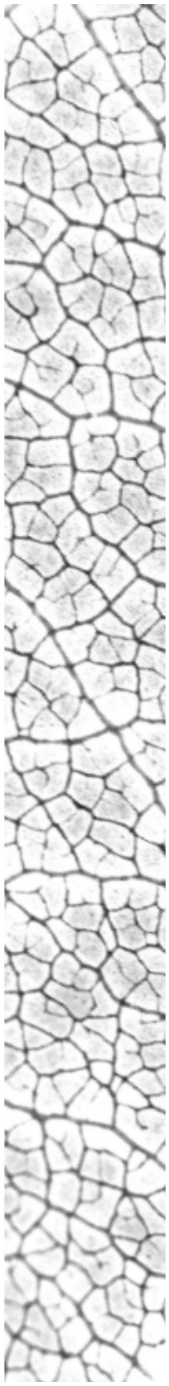

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Air pollution by road traffic and its measurement methods

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Abstract

Background: Environmental problems of cities are associated with excessive concentration of population, transport and industrial enterprises in relatively small areas with anthropogenic landscapes formation, far from the state of ecological balance. The present study is aimed at developing recommendations for environmental measures aimed at the management of anthropogenic tendencies, forecasting the state of air pollution, carrying out the necessary environmental measures and developing a system for managing road influences on the urban environment.

Material and Methods: Assessment of air pollution and conclusions about the need to develop technical and organizationally-technical measures to reduce emissions of vehicles is based on the analysis of the concentrations of impurities obtained by calculation and instrumental methods. In the course of the study, the methods of statistical processing and analysis of measurement data were used. Toolkit for modeling the state of the atmosphere and programming allowed developing a software calculation complex that automates and visualizes the analysis tasks of the traffic flow.

Results: The authors substantiate the toolkit for assessing the environmental situation of the city and identify patterns of its formation. The intensity of traffic flow on the streets of the city – highways is defined. The regularities of pollution fields' formation depending on the territory and intensity of traffic flows are revealed. The software to calculate the map of the city atmosphere pollution by motor transport emissions is developed.

Conclusions: The task is solved of a comprehensive assessment of air pollution degree in the city by impurities emitted from the exhaust gases of cars, separately from pollutants coming from stationary sources of pollution. The study allows predicting the effectiveness of various environmental measures related to civil construction, construction of new roads, regulation of traffic flows.

Keywords: air pollution, air emissions, computer program, concentration calculation, cars

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INTRODUCTION

The rapid growth in the number of vehicles in the fleet increases the negative processes associated with motorization, which are particularly acute in large cities. In many large cities of Russia and the world emissions of motor transport prevail over emissions of stationary sources. The danger of vehicles as a source of air pollution is exacerbated by the fact that harmful substances enter the air almost in the area of human respiration. Atmospheric air is an essential life-supporting component of the ecosystem, so its pollution is a powerful and permanent factor of impact on humans and the environment.

The specific nature of air pollution by vehicle emissions is manifested, first of all, in the complex spatial structure of urban highways, low location of emission sources above the ground, their immersion in urban development, as well as close proximity to recipients. As a result, with the total share of transport in the mass emission of pollutants into the atmosphere equal to 35 - 60%, the corresponding share in the pollution of the surface air layer in cities reaches 70-90%. All this leads to the fact that vehicles in cities create extensive and sustainable areas, within which the sanitary and hygienic standards of air pollution several times are exceeded. Therefore, road transport should be classified as the most dangerous sources of pollution,

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the assessment of the impact of which on the air is objectively necessary in relation to the design of urban transport infrastructure.

A significant contribution to the study of air pollution by automobile-road complex was made by the following Russian and foreign researchers: studies of substances' concentration emitted into the atmosphere by motor transport, in specific cities and countries is considered (Dementiev 2016, Gurtyak 2016, Jandacka et al. 2017, Perevedentsev et al. 2014, Zhang et al. 2016). The problem of air pollution by road transport in Russia (Irkutsk, Kazan, Kerch, Chita, and Penza), Germany (Kiel), and Mongolia (Ulan Bator) is considered. The calculations of pollutants' emissions entering the air from cars are presented. Assessment and analysis of air pollution dynamics by road and the prediction of the likely consequences are given in studies (Egorova 2014, Golohvast 2014, Iodice and Senatore 2015; Lozhkina and Lozhkin 2015, Podlipenskaya et al. 2012, Radkevich 2013, Shireesha and Suresh 2016, Ulanova et al. 2016, Zubkova and Stepanova 2016). The authors of these works on the basis of the data that were obtained earlier, have identified the most negative impact that road transport has on the quality of atmospheric air, identified the relationship of the landscape and the concentration of harmful substances near the road complex (Lyapkalo et al. 2012, Podlipenskaya et al. 2017, Scherbatyuk 2014, Shagidulin and Shagidulin 2016, Sotnikov et al. 2008).

We believe that the problem can be solved by mapping the atmosphere - organization of automated posts' territorial networks of its characteristics' nature measuring on the basis of the developed methods of calculation (Sharma and Swami 2012, Stepanova et al. 2016). In view of the extremely high spatial and temporal variability of air pollution fields created by vehicles, it is planned to develop software based on calculating air pollution by vehicles capable to form a visually oriented picture of the atmosphere at the current time, with the definition of the characteristic scale of pollution.

MATERIALS AND METHODS

Characteristics of Vehicles as a Source of Air Pollution with Harmful Substances

Transport flows have the greatest impact on the level of environmental pollution. The main influencing factors are: composition, intensity, speed and acceleration of traffic flow; technical level and operational condition of vehicles; volume and range of goods transported. The volume of freight transportation is dictated by the economic characteristics of the production infrastructure, competition of other modes of transport, passenger – demographic factors, the level of welfare of the population.

In order to prevent a local environmental disaster, it is necessary to understand the maximum permissible level of saturation of local areas with the car Park and transport infrastructure. Initial information – the growth rate of the number of vehicles parks, the length of roads, the intensity of use, the technical level and technical condition of road transport equipment, road network.

Environmental pollution by transport complex conditionally can be divided into technological (from road-building machines, special vehicles of road companies, asphalt plants, bases of equipment – from point sources) and transport ones (from traffic streams–linear sources). The volume of transport emissions of harmful substances into the atmosphere on public roads is almost twice as much as the volume of technological emissions. The annual volume of technological emissions of CO, C_xH_y, NO_x is 5-10 times less than the volume of emissions of these substances by transport flows. Transport emissions include toxic substances with exhaust gases of cars, products of tire wear, antifriction materials, oil products, service liquids, worn parts and units, including tires, batteries.

Different estimation methods are used to determine the concentrations of harmful impurities in the air near highways and engines exhausting gases. One of these is the analysis of individual gas samples taken discretely and in continuous measurements. In this study for calculations of pollutant emissions, we used data that were collected, following the instructions for collecting the initial information for calculations of pollutants emissions according to the technique used. The list of benchmarks is provided in a sequence that is highly recommended when conducting surveys of atmospheric pollution: the traffic intensity in the given time interval grouped by engine type (gasoline: cars, trucks, buses; diesel: trucks, buses); mileage emission of polluting substances (CO, CH, NOx, C, Pb, SO2) when driving on the track vehicles of this type.

Methods for Calculation of the Amount of Pollutants Emissions into the Atmosphere by Road Transport

The main purpose of this technique is to calculate the emissions of pollutants from traffic flows when driving cars are on urban highways, and it can be used to assess the environmental impact indicators, justify the need for environmentally-oriented measures for traffic organization, evaluation of alternative design solutions for traffic management and comparative technical and economic assessment of options for design solutions for traffic management.

The technique takes into account the emission of the following pollutants: carbon monoxide (CO); hydrocarbons (CH); nitrogen oxides (NO_x); particulate matter (soot) (C); sulfur dioxide (SO_2); lead compounds (Pb).

The influence of traffic conditions in the traffic flow on the emission of pollutants is primarily manifested through the ratio of established and unsteady traffic

modes due to the organization of traffic. Therefore, in General, the value of the emission of cars i-th pollutant M_i on the street by the length of l per unit time can be determined by the formula:

$$M_i = M_{li} + D_i \quad (1)$$

where: M_{li} – is the emission of the i-th pollutant in continuous traffic flow, g/h reflects the inevitable part of the emission, determined by the technical level and condition of vehicles, speed, traffic intensity and road conditions;

D_i – additional emission of i-th pollutant connected with the delayed vehicles, g/h - reflects an increase of emissions caused by braking and acceleration of vehicles as well as engine operation at idle.

To implement this technique, the following *calculation algorithm* is used:

1. The section of the city transport network is represented as separate elements of the street-road network (SRN): runs (n) and intersections (j);
2. The emission of pollutants M_{li} is determined for each stage, based on the direction of movement, the length of the site, the number of lanes and traffic intensity in this direction;
3. An additional emission D_i is calculated for each intersection. The calculation for controlled intersections is based on the representation of each intersection as a set of controlled directions (PH), including one or more geometric directions of vehicles' movement on the approach to the intersection, having common lanes and controlled by a common traffic light signal. Each PH is characterized by the number of vehicle stops, engine idling time and speed at the input and output sections. For unregulated intersections of equivalent roads, D_i is determined for each direction of traffic, and for unregulated intersections of non-equivalent roads-only for secondary one;
4. Traffic flow is divided into five groups of calculated vehicles:
   - *Calculated car (CC)* - the average model of the car, reflecting the existing distribution of cars with engines of different capacity in the stream;
   - *Calculated truck with a gasoline engine (CTG)* - the average model of a truck with a gasoline engine, reflecting the existing distribution of trucks of different cargo capacity in the flow;
   - *Calculated truck with diesel engine (CTD)* - the average model of a truck with a diesel engine, reflecting the existing distribution of trucks of different cargo capacity in the flow;
   - *Calculated bus with gasoline engine (CBG)* - the average model of the bus with a gasoline engine, reflecting the existing distribution of buses of different classes in the stream;
   - *Calculated bus with diesel engine (CBD)* – the average model of the bus with diesel engine, reflecting the existing distribution of buses of different classes in the stream.

According to preliminary estimates, for large cities of Russia: the share of CTG is 71%, CTD-29% of the total number of trucks, and for the CBG – 37%, CBD – 63% of the total number of buses in the flow. In cases where for a particular city the ratio between these calculated types of vehicles differs significantly from the above mentioned, it is determined experimentally in the preparation of the initial data for the calculation. With the already available source data, one can start to produce the basic calculation.

Calculation Technique of the Emissions' Amount into the Atmosphere for the Intersections of the Road Network

Calculation of pollutants emissions can be made for different schemes of sections of the road network, including depending on the conditions of road. One can consider the calculation of pollutants' emissions for the element of the *road network with a controlled intersection*.

Driving conditions: V= 45-60 km / h (for input and output directions);

Crossing conditions for a given PH: the number of cars in the queue does not exceed the capacity of the intersection.

The emission of the i-th pollutant for the input and output direction M_{li} (g / h) is determined by the formula:

$$M_{li} = \sum_{k=1}^{5} m'_{lik} \cdot l_n \cdot N_{kn} \quad (2)$$

where: m'_{lik} –mileage emission of the i-th pollutant by the car of the k-th calculated group, g / km;

l_n – length of the n-th run of the input and output direction, km;

N_{kn} –the intensity of vehicles' movement of the k-th calculated group on the n-th stretch of the input or output direction, auto / hour.

The additional emission of the i-th pollutant D_i (g / h) for the corresponding PH of each input direction is determined by the formula:

$$D_i = \sum_{k=1}^{5} [m'_{sik} + m_{xxik} \cdot t_{xx}] \cdot N_{ок} \quad (3)$$

where: m'_{sik} –additional emission of the i-th pollutant because of the stop of the car of the k-th calculated group;

m_{xxik} - emissions of the i-th pollutants during operation of the vehicle engine of the k-th calculated group at empty run, g/min;

t_{xx} –engine idling time for the corresponding PH, min;

$N_{ок}$ –the number of stopped cars of the k-th calculated group at the corresponding PH, auto / hour.

For unregulated intersections of equivalent roads, the emission of the i-th pollutant for the input and output direction M_{li} is determined by the formula (2), and the additional emission of D_i (g / h) by the formula:

$$D_i = \sum_{k=1}^{5} [m'_{sik} + m_{xxik} \cdot t_{xx}] \cdot N_{ок} \qquad (4)$$

where: t_{xx} –engine working time at idle running for the input direction, min;

$N_{ок}$ –number of cars stopped at the entrance direction, auto / hour;

For an *unregulated junction of non-equivalent roads* of the i-th pollutant for the input and output direction M_{li} is determined by the formula (2), and the additional emission D_i by the formula (4) only for the secondary input directions.

For circular intersections, the length of the stretch for the input and output directions is determined from the center of the ring. The total emission of the i-th pollutant for the element of the road network section is determined by summing all the values M_{li} and D_i.

Software requirements

Most software products help to improve the efficiency of automatic air pollution control stations, to automate the collection of data from analytical instruments, to perform computer audit of laboratory analysis, to carry out operational internal control of stations [3]. They are not in the public domain and are aimed at working with automatic air pollution control stations. In addition to the existing and updating atmospheric data from monitoring stations a common user can only have an access through Internet resources, where information is often presented in a compressed form. It is not convenient to work with such a presentation of information, and the prediction of air pollution from compressed data is limited to long-term or perspective one at any rate.

One of the ways to increase the quality control of the ecological state of atmospheric air pollution degree in city by impurities emitted with the exhaust gases from vehicles and simplify the work with large volumes of information obtained in the course of monitoring of atmospheric air, is the development of specialized software for automation of monitoring stations of atmospheric air pollution, as well as for applied use in predicting air pollution.

In order to optimize the development, we have established the following requirements for the software package:

1) The Calculation should be carried out in accordance with the technique “Calculation of emissions of pollutants into the atmosphere by vehicles on urban highways»;
2) The Output of information should be carried out using an electronic map of the city (for example, Kazan);
3) Issuance on the interactive map of the city involves the display of all the results of the calculation for a single pollutant at the same time;
4) There is a database of all information on air pollution, on the basis of which it is possible to carry out a comparative analysis of pollution in the city.
5) There is a possibility of a graphical representation of the concentrations’ dependencies or fractions of the pollutant on time.

RESULTS

The Description of the Software System to Assess the Degree of Atmospheric Air Pollution in the City

The author’s software has the following functions:

- data collection
- processing of collected information;
- keeping of the processed information in the database;
- presentation of data contained in the database in tabular and graphical form;
- export / import of data on user’s request;
- work in automatic mode;
- The choice of graphical display dependency;
- Analysis of the selected data in order to identify: exceeding of the maximum permissible concentration of the pollutant, the number of such exceeding and their frequency; the highest concentration of substances, etc.

The program contains a visual list of control stations and provides for their sorting by Autonomous districts of the city. The data from any control station, displayed in a table, can be displayed either in full or for a specified period of time. The data collection consists in obtaining information, which provides information for the last 48 hours on the concentrations and proportions of the pollutant in the air of the city. Data collection can be carried out both in manual mode, when the user in the data collection module makes a choice: for what automatic station of air pollution control to collect – either for a particular or for all available ones, and in automatic mode, when the program with a specified periodicity collects information for all available automatic stations of air pollution control. On one chart, one can display the dependencies for all pollutants that are recorded by the selected automatic air pollution control station, and one can select the dependencies that are of interest to the user.

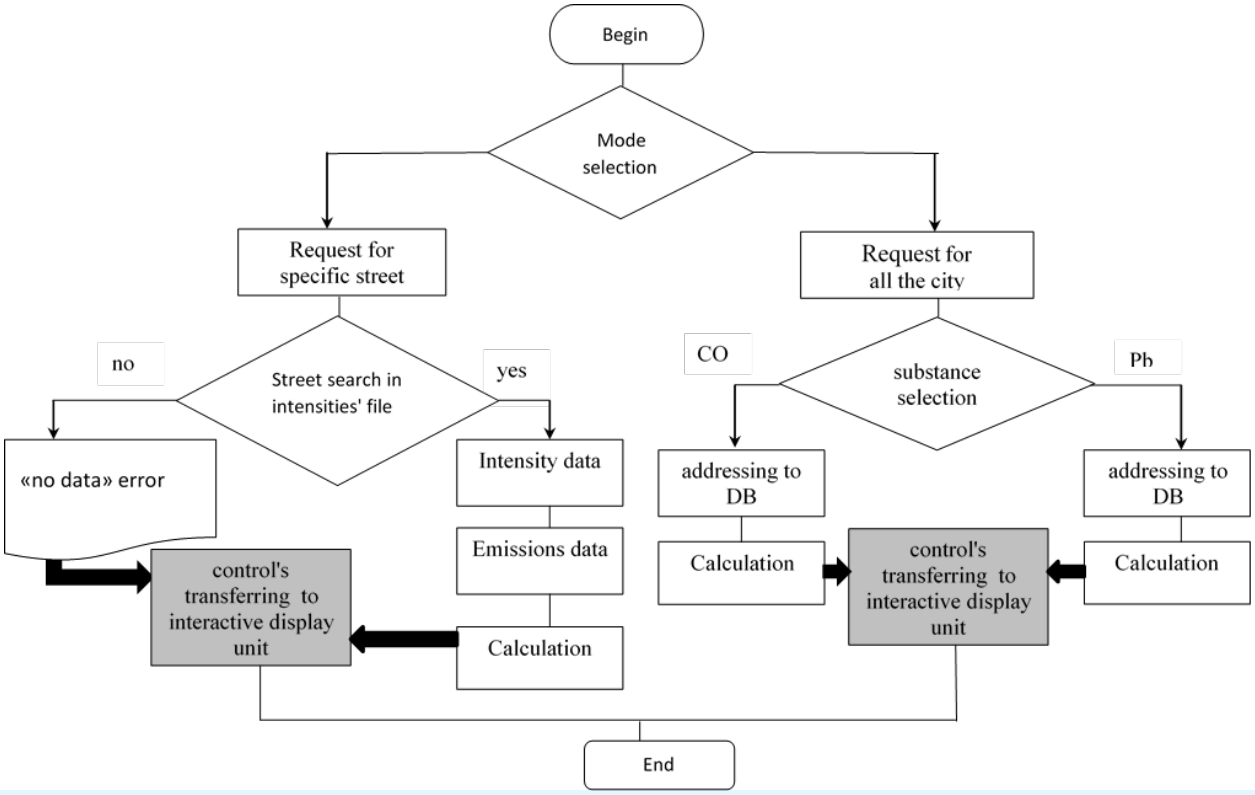

Fig. 1. The scheme of the calculated unit of the software complex of atmospheric pollution calculation from cars

The presented functions of the developed software complex are performed by three special modules of the program: source data processing unit, the calculation part, the display unit of the received information on the screen.

The main interface of the software application is represented by the display module. It displays all the information collected, processed and recorded in the databases after the data collection module's work is completed. The program provides a special module used to analyze the collected and structured in chronological order information about the concentrations of pollutants. It implements a wide range of relevant functions and performs information analysis commands, the results of which are tabular and graphical data with the ability to export them in the form of reports in an MS Excel document.

The process of processing the source data should be presented in the form of text files. Before starting the work, the input data, in the form of files, are loaded into the system within the access mode.

By default, only data processing is allowed, data editing is available only to registered users. The data access key must be used to modify the input data. The password file is stored in a specific folder, and its contents are stored encrypted. Changing the password is available only to previously registered users.

Further, in the part of the program complex, a direct calculation of the amount of pollutants' emissions by the formula (2) is made using the **Table 1** data.

Table 1. Run-off emission of pollutants when driving on the passage (m'_{lik})

Type of vehicles	Mileage emission of pollutants, g / km					
	CO	CH	NO_x	C	Pb	SO_2
CC	9.8	2.2	1.9	-	0.02	0.07
CTG	68.4	6.4	6.1	-	0.03	0.21
CTD	4.6	2.9	10.2	0.38	-	1.47
CBG	93	7	7.9	-	0.04	0.30
CBD	5.8	2.7	9.1	0.38	-	1.59

The obtained data are displayed in the interactive part of the software complex "street tracking", on the electronic map of Kazan. In the output mode of information about pollution throughout the city: the source data in the form of files are loaded into the system; the type of pollution is selected, CO or Pb, according to which it is necessary to display the results; the interaction of the program with the file of intensities and mileage emissions takes place; calculation of emissions' amount from all available data in the intensity file is carried out; output of information on the map, by determining the coordinates for output is fulfilled (**Figs. 1, 2**).

When the list of streets is accessed, a processing procedure is performed: the name of the selected street is recognized and the input intensity file is interacted with. In the loop, a line-by-line comparison of the record obtained at the previous stage and the data contained in the file by the street code is performed. If the result of the comparison is negative after the end of the cycle, the main window displays the message "no data", which

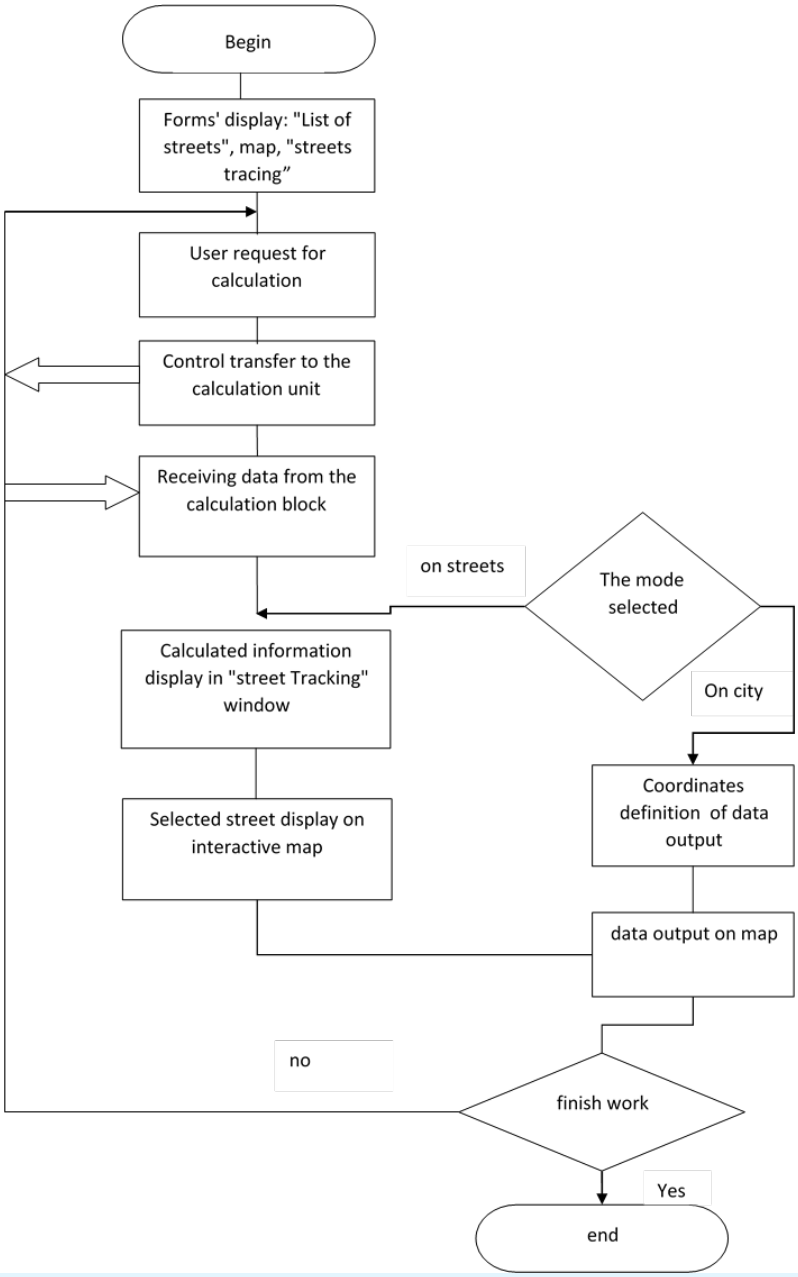

Fig. 2. Operation scheme of information interactive display unit

means that there are no intensity values for the selected street in the file. If the result of the comparison is positive, the found line from the file will be entered into the intensity array. Next, there will be an appeal to the file of emissions. The next step is the basic calculation of the amount of pollutant emissions. After that, the result of the calculation will be displayed in the main window of the program, which will also display the street name and its code.

As a result of the work of the program complex, in addition to the visualized data representation, a database - structured storage of collected information about the state of the atmosphere is formed (a fragment of measurements is given in **Table 2**, the results of one day are presented).

These data are the results of calculations of the software complex for calculating the amount of pollutants' emissions into the atmosphere by road. The described software application can be used as an information base that allows you quickly to find enough complete information on a particular control station and for a particular pollutant for a period of time from 1 hour to several years. The obtained data can be used in the framework of environmental control, in the design of new civil structures and transport networks.

Table 2. Calculated values of road transport emissions into the atmosphere (example is given for Kazan city)

Streets	CO	CH	NO	C	Pb	SO2
Magistral	2019.9	532.1	613.1	5.7	3.54	39.53
Tatarstan	2981.3	1245.3	1347.8	8.74	9.21	76.08
Kirov	2156	899.6	1011.1	76	6.29	61.84
Levobulachnaya	3639.3	1386.6	1537.5	13.68	10.36	98.7
Pravobulachnaya	3639.3	1386.6	1537.5	13.68	10.36	98.7
Fuchic Julius	2771.6	1203.6	1307.6	7.6	8.64	72.25
Dostoyevsky	3825.6	1173.9	1173.3	3.42	8.66	53.68
Cutuy Adel	3664.1	1173	1290.5	9.88	8.41	76.92
Yershov Nikolai	3112.1	1238.9	1288.9	6.46	9.35	67.44
Syberian tract	5915.3	1759.6	1905.9	14.44	12.64	115.44
Gubkin Academician	2212.3	701.4	769	6.08	5.09	46.43
Gvardeyskaya	3527.2	1281.4	1323.2	6.08	9.57	67.53
Carl Marks	3306.4	1547.6	1547.4	16.08	11.98	77.28
Gorkiy	4014.2	1023.2	1040.2	5.32	7.53	54.09
Decabrists	3811.1	1244.5	1311.9	8.74	9.28	76.01
Vosstaniya	3891.2	1077.7	1118.7	6.46	7.94	60.62
Gorkovskiy route	2733.1	1096	1067.6	3.8	8.91	50.99
Lieutenant Schmidt.	3338.4	724.4	800.3	6.84	4.88	49.75
Dementiev	3596.1	908.6	1010.9	9.12	6.34	64.63
Krasnocockshaiskaya	5502.7	1221.7	1338.5	11.78	8.56	83
Belomorskaya	2918.8	1150.7	1209	7.22	8.74	66.94
Clara Tsetkin	2539.3	821.8	930.5	8.36	5.83	59.13
Chuikov Marshal	3025.7	917.5	936	4.18	6.8	47.08
Yamashev Khusain Prospect	4916	1398	1535.3	12.16	9.93	92.16
Lomzhinskaya	5341.7	1219	1355.7	12.16	8.38	85.15
Parin academician	3478.4	1110.7	1171.5	6.48	8.08	62.23
Technical	3441.2	830.1	931.7	8.74	5.72	60.27
Gabdulla Tukai	2963.3	1037.3	1093.9	6.46	7.69	60.25
Narimanov	3350.9	375.5	936	6.46	6.25	53.31
Rotornaya	2915	791.5	854.1	6.46	5.7	50.5
Galiaskar Camal	4453.3	1466.1	1750.9	20.9	10.3	127.96
Mavlutov	3564.7	1286.4	1320.1	6.08	9.73	64.05
Esperanto	3063.1	948.6	948.1	3.8	7.23	46.25
Journalists	7381	1695.5	1740	9.5	12.19	90.95
Tolstoy	4168.5	1698.3	1819.2	12.54	12.95	104.17
Ibragimov Prospect	3916.2	1512.4	1575.7	9.12	11.79	87.56
Pavlukhin	3891.2	1077.7	1112.7	6.46	7.97	60.62
Corolenco	5082.2	1368.1	1511.1	13.3	9.78	95.01
Leningradskaya	3410.3	1108.9	1170.3	6.46	8.03	63.03
Aidarov	3373.3	1431.3	1688.6	17.86	9.95	114.56

DISCUSSION

Environmental problems of cities are associated with excessive concentration of population, transport and industrial enterprises in relatively small areas, with the formation of anthropogenic landscapes, which are very far from the state of ecological balance. Analysis of the dynamics of pollutants' emissions demonstrates a steady increase in gross emissions into the air of the city (Gerasimov et al. 2015, Golokhvast 2015, Suleiman et al. 2016, Zakharenko 2017). Active and widespread operation of cars greatly worsens the environment, pollutes the air, water, rainfall, atmosphere. And this situation can lead to many health problems. Thus, the respiratory system suffers greatly, because harmful substances of exhaust gases almost immediately get into it, irritate the mucous membranes, and clog the lungs and bronchi. Due to respiratory disorders there is a lack of oxygen in all tissues of the human body (Shagidulin and Shagidulin 2016, Volvach and Batrakov 2008; Zhang et al. 2016). In addition, hazardous road transport compounds are carried with blood and deposited in various organs, and the effects of such contamination can be seen years later in the form of chronic or even cancer.

The changes associated with the negative impact of vehicles are becoming more and more global every year, and over time they can lead to the collapse of the ecosystem existing on the planet earth, which will affect the life of mankind, air, and atmosphere. The need to take into account emissions from various sources, their mutual influence emphasizes the work of environmental services in large cities in this area. Determination of surface concentrations (dispersion) of pollutants by calculation allows simplifying and speeding up the calculation procedure, to obtain a clear picture of the dispersion of harmful substances' emissions in the surrounding area in relation to the actual scale of the area, to assess the effectiveness of various measures to reduce emissions.

CONCLUSION

Atmospheric air is an essential life-supporting component of the ecosystem, so its pollution is a powerful and permanent factor of impact on humans and the environment. The continuous increase in the intensity of vehicles traffic contributes to a significant increase in air pollution of large cities and industrial centers. In this regard, the authors have developed a software package for calculating the amount of pollutants' emissions into the atmosphere by road transport, contributing to the identification of excess in concentrations of harmful substances, the frequency of exceeding and their regularities. The information basis for solving the problems of air pollution mapping in our study are the data of the program complex for calculating air pollution by transport, taking into account the extremely high spatial and temporal variability of air pollution fields created by vehicles.

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