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JUSTIFICATION FOR THE ROAD TRANSPORT STREAM PARAMETERS ON BASIS OF THEIR ECOLOGICAL MONITORING

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Abstract:
The results of motor transport flow parameter complex analysis that affect the degree of the ground layer pollution in the atmosphere of cities are presented. It has been suggested that not only the emissions of exhaust gases from car engines, but also the wear products of vehicle assemblies and units should be taken into account during the environmental monitoring of motor transport flows. The regularities of harmful substance mass emission change on the parameters of the traffic flow were determined. They developed the mathematical model of the atmosphere surface layer contamination according to the parameters of the motor traffic flow taking into account the wear products of vehicle units and assemblies. They developed the algorithm for the ecological monitoring of motor transport flows, based on the dose approach and the predictive assessment methodology for the concentrations of pollutants in the surface layer of motor road atmosphere. A dose approach to the assessment of toxicity in the most polluted areas of SRN allowed to estimate the degree of surface layer toxic pollution concerning the atmosphere of motor roads in the districts of the city of Orenburg (0.0003 of total toxic doses on the average) and determine the greatest contribution to the total toxicity (benz(α)pyrene 68, 65%, acrolein 19.73%, formaldehyde 7.81%). They developed the program to inform road users about the pollution degree of the atmosphere surface layer on traffic flows.

Key words: *road transport flows, transport work, emissions of harmful substances, ecological monitoring, exhaust gases, automobile tires, brake mechanisms, road surface.*

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INTRODUCTION:

In modern megacities, because of the congestion of motor roads, the main source of environmental pollution is motor traffic, which forms a complex of the most toxic harmful substances (HS) in the surface layer of the atmosphere and on the surface of highways [1, 2]. Moreover, the motor vehicles (MV) of M1 M2 and N2 categories contribute up to 90% of atmospheric pollution and create the sections of the street-road network (SRN) exceeding the maximum allowable concentrations (MAC) at a certain traffic intensity. These circumstances necessitate the management of road transport, taking into account the ecological situation on the roads of the city. Nowadays, the phased introduction of environmental classes to Euro-6, aimed at the reduction of HS mass emissions with exhaust gases (EG) of cars does not ensure the ecological safety of road traffic, since the influence of secondary and tertiary products of interaction between the engine EG of a car, the products of tire wear [3], road surface, asphalt fumes [4] and industrial background of urban pollution on the ecology of cities is not taken into account. The studies [5, 6] have shown that the main part of the atmosphere surface layer pollution is not associated with single EG emissions, but with the accumulation of SAH, soot and other tire wear, brake mechanisms, pavement and asphalt evaporation products lifted by motor traffic to the height of 10 m from a roadway. At the same time, it is the solid particles (PM 10, PM 2.5) that develop as the result of MV unit and assembly wear and tear [7], adsorb toxic substances that can penetrate into the lungs, causing bronchial asthma, oncological and other diseases [8, 9]. Therefore, during the evaluation of the environmental safety of cities, an integral approach is needed that takes into account not only the contribution of each of the emission sources, but also the parameters of the traffic flow dynamically changing in urban conditions.

MATERIALS AND METHODS:

According to the system approach, a functional model was developed [6], which made it possible to identify the main factors of the surface layer pollution concerning the atmosphere of motor roads by motor transport flows and to assess their influence on the composition and the concentration of pollutant emissions. At that it is justified that the main parameters of motor transport flows that affect the mass of HS emissions are the following ones: intensity, composition and average speed. In order to substantiate the parameters of traffic flows in the areas of SRW, the methodology for environmental monitoring was developed based on a new approach that takes into account the toxic effects of exhaust gas, tire wear products, brake mechanisms and road surface [10]. In order to implement the proposed approach, a mathematical model was developed for the quantitative estimation of HS mass ejection from the motor traffic flow ($M_{BBавт.потока}$,г):

$$M_{BB\ авт.поток} = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} M_{ijk_{ОГ\ ДВС}} + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} M_{ijk_{изн.шин}} + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} M_{ijk_{изн.дор.покр.}} + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} M_{ijk_{изн.торм.мех.}}, \quad (1)$$

where $M_{ijk_{ОГ\ ДВС}}$, $M_{ijk_{изн.шин}}$, $M_{ijk_{изн.торм.кол.}}$, $M_{ijk_{изн.дор.покр.}}$ – emission masses of the i-th HS from the EG engine, tire wear products, brake mechanisms, the pavement of j-th car of k-th category, g; I - the amount of HS; J - the number of vehicles of one category; K - the number of categories.

In order to assess the ecological safety of the motor transport traffic, taking into account the transportation work during cargo and passenger transportation, we introduced a new parameter - the total mass of VS in the traffic flow ($M_{поток}$, t) and the general view of the mathematical model is set to determine the total mass of HS emissions from traffic flows ($M_{BB\ авт.поток}$, g):

$$M_{BBавт.поток} = (k_{vОГДВС} \cdot m_{ОГДВС} + k_{vизн.шин} \cdot m_{изн.шин} + k_{vизн.дор.покр} \cdot m_{изн.дор.покр} + k_{vизн.торм.мех} \cdot m_{изн.торм.мех}) L t M_{поток}, \quad (2)$$

where $M_{ОГ\ ДВС}$, $M_{изн\ шин}$, $M_{изн.дор.покр.}$, $M_{изн.торм.мех.}$ – the mass of HS of motor vehicles, tire wear products, pavement and the brake mechanisms from the traffic flow, g, respectively;

$m_{ОГ\ ДВС}$, $m_{изн.шин}$, $m_{изн.дор.покр.}$, $m_{изн.торм.мех.}$ – specific emissions of HS from motor vehicle engines ($113,0$ г/т·км), tire wear products ($0,1$ г/т·км), pavement ($0,6$ г/т·км), brake mechanisms ($0,014$ г/т·км) respectively, taking into account the mass of the motor traffic;

$k_{vОГ\ ДВС}$, $k_{vизн.шин}$, $k_{vизн.дор.покр.}$, $k_{vизн.торм.мех.}$ – correction factors for the change in the mass of Hs emission for EG from vehicle engines $k_{vОГ\ ДВС} = (0,14 + 0,04\,|\,v - 64,95\,|^{0,89})$, tire wear products $k_{vизн.шин} = -6,55 \cdot 10^{-5} v^2 + 1,49$, road surface $k_{vизн.дор.покр.} = 1,01 + 1,66e^{-0,06v}$, braking mechanisms $k_{vизн.торм.мех.} = 3,12e^{-0,02v}$ taking into account the average flow rate; L – the length of SRN section, km; t – alculated period of time, h.

The parameters of the traffic flow were determined experimentally during summer (including the use of web cameras located at the crossroads of the city), during the periods of maximum intensity near traffic lights taking into account climatic conditions. The study of air samples according to the expanded list of HS toxicity was carried out on the basis of accredited laboratories using standardized and certified methods and equipment.

The normalization of component sum toxicity of the surface layer for the atmosphere of motor roads was suggested to be estimated from the total dose of typical HS toxicity in air, with the volume of one cubic meter $(\sum_{i=1}^{n} C_i / CL_{50})$. The dose approach adopted by us is based on the achievements of the national toxicology school scientists [11], recognized in international practice (Magnuson H.J., Olson K.). The regional permissible amount of toxic doses of chemicals that are capable of making an aerogenic impact on the residents is proposed to adopt as an indicative permissible level of pollution for roads. In this case, we suggest to quantify the total toxicity at the level of no more than one conditional toxic dose.

RESULTS AND DISCUSSION:

The approbation of the developed method of ecological monitoring of motor transport streams taking into account the toxicity of HS emissions was carried out by setting up and carrying out an experimental calculation study according to the proposed algorithm of motor traffic flows for ecological monitoring (Figure 1) in relation to the busiest sections of the Orenburg SRN.

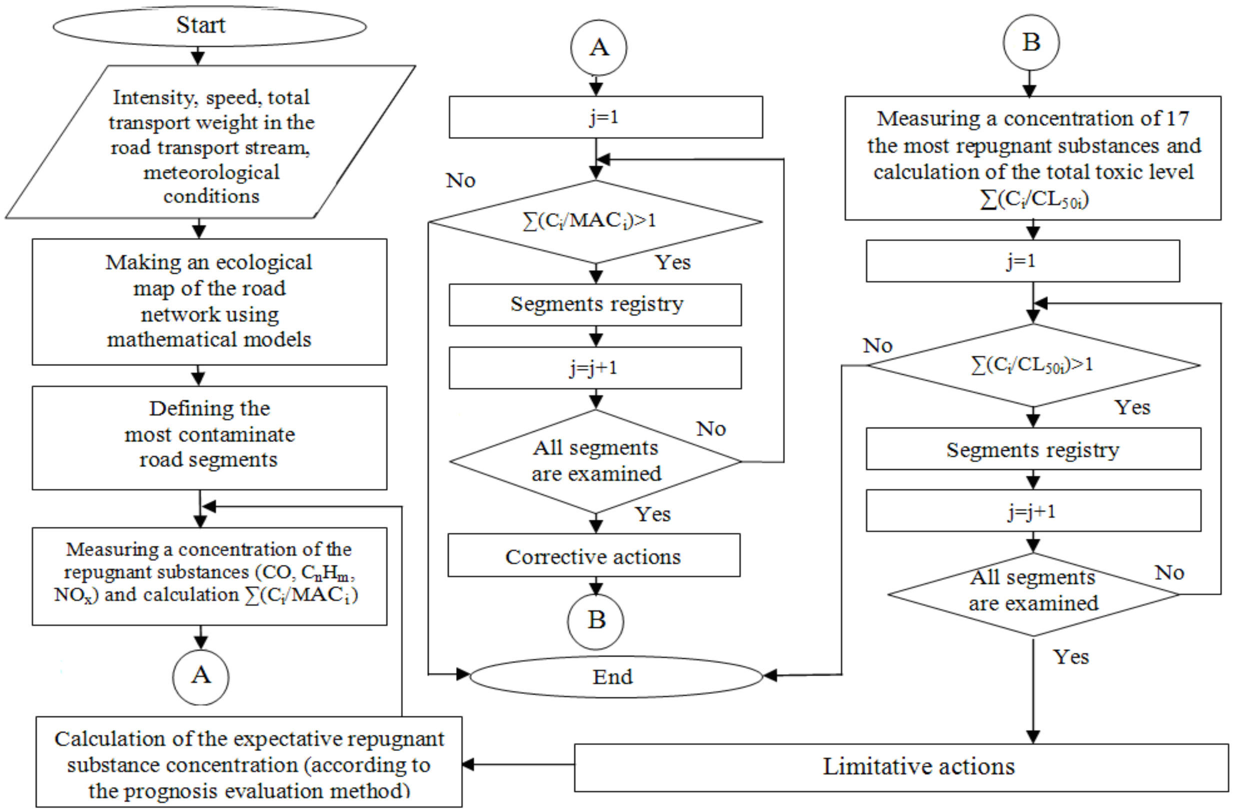

Fig. 1. Algorithm of the transport streams ecological monitoring based on the dose principal for harmful substance toxicity evaluation

The intensity of the motor traffic flow on the SRN varied from 385 to 3159 vehicles per hour, making 1811 vehicles per hour on the average (Table 1). The average speed of road traffic in the city of Orenburg was 31 km/h. The total mass of VS in the flow was calculated, as well as the predicted mass of HS emissions for each SRN segment, taking into account the categories of VS.

Table 1. Quantitative characteristic of the transport stream on Orenburg roads (the fragment)

Street	Predicted stream intencity, aut./h	Transport stream mass, t	Average speed, km/h	Expectative repugnant substance mass, g/h
Donguzskaya str.	2287	4313	45	35160,85
Salmyshskaya str. / Rodimtseva str.	**2019**	**4098**	**20**	**61708,54**
Chkalova str.	3016	5714	45	46582,22
Dzerzhinskogo avenue	1570	3309	30	40904,39
Rodimtseva str.	1640	2844	30	35156,27
Gagarina av./ Mira str.	**3159**	**6209**	**30**	**76752,90**
Chicherina str.	1427	2934	40	28119,20
Pobedy av./ Shevchenko str.	**2825**	**5190**	**30**	**64156,48**
Tereshkovoy str./ Tehnicheskaya str.	1480	3054	40	29269,27
Tsvillinga str. / Nevelskaya str.	**1955**	**3639**	**20**	**54796,82**
8 Marta str. / Volodarskogo str.	**1552**	**3357**	**20**	**50550,41**
Pobedy av. / Karagandinskaya str.	**2652**	**5059**	**20**	**76179,48**
Proletarskaya str./ Shevchenko str.	1894	3835	20	57748,23
Tereshkovoy str. / Orskaya str.	**2858**	**5258**	**20**	**79176,06**
…	…	…	…	…
Average in town	1811	3501,54	30,58	42729,19

The developed mathematical model and the program SigmaPlot 11.0 allowed to determine the theoretical function of HS emission mass change from the average speed and the total mass of ATS in the flow (Fig. 2) and to choose the optimal parameters of traffic flows on the most polluted areas of SRN. It was established that the adjustment of motor transport flow parameters allows to reduce the degree of pollution of the atmosphere surface layer to the minimum possible one in various ways: by changing the duration of the traffic light signal in on-line mode; using controlled road signs and placards; quoting the number of ATS (replacing numerous M2 buses for M3 buses with increased passenger capacity); limiting or redistributing cargo ATS using the program "Econavigator" of the category N2 and N3 during peak hours.

In order to assess the environmental safety of road traffic, we analyzed the total toxic effects of the entire HS complex, which can be accumulated in the surface layer of the atmosphere of highways (Table 2) on the most polluted areas of the city SRN (Table 1). Control measurements in the early morning hours showed the absence of background pollution from industrial enterprises of the city.

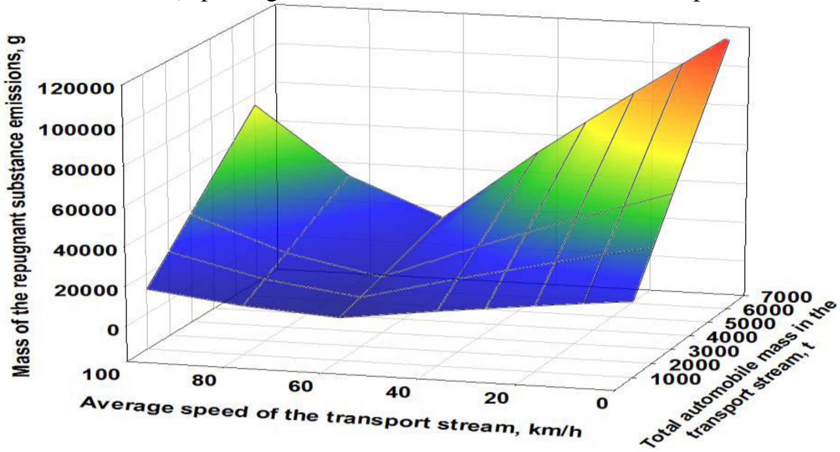

Fig. 2. Dependence of the mass emission change from the transport stream parameters in the intersections

The study showed the presence of aromatic hydrocarbon high concentrations, in particular, acetone, benzene and chlorobenzene. Despite the fact that the total dose of HS toxicity was 0.0003 units in the city of Orenburg on the average, the ratio of actual concentration Ci relation to their MPC was exceeded by 2.48 times (Table 2). Moreover, the excess of MPC of these substances is more typical for the central part of the city and for the busiest intersections, especially during peak hours. It has been found that significant concentrations of HS may be explained by the high wear of tires (benzene, toluene and xylene), braking mechanisms (iron), pavement (solid particles) or significant emissions from exhaust gases (acrolein and benz (α) pyrene) or by the release of asphalt fumes (styrene, formaldehyde). The rating range of HS danger released to the ground layer of the atmosphere allowed to determine the substances that make the greatest contribution to the total toxicity (benz(α)pyrene 68.65%, acrolein 19.73%, formaldehyde 7.81%).

Table 2. Average results of the toxic doses calculation and the dosing toxicity rating of the components in the atmosphere surface layer in Orenburg (the fragment)

Repugnant substance	Average concentration in town, mg/m^3	MAC, mg/m^3	C_i/MAC_i	CL_{50}, mg/m^3	Amount of the toxic doses C_i/CL_{50}	Percent of the whole toxicity, %	Dosing toxicity rating
Benzapyrene (mkg/100 m^3)	0,0000005	0,000001	0,54285714	0,0024	0,000226190	68,6522	1
Acrolein	0,013	0,03	0,43333333	200	0,000065000	19,7285	2
Formaldehyde	0,010285714	0,05	0,20571429	400	0,000025714	7,8047	3
Phenol	0,002051429	0,01	0,20514286	330	0,000006216	1,8868	4
Chlorbenzene	0,049142857	0,1	0,49142857	15000	0,000003276	0,9944	5
Benzol	0,044157143	0,3	0,14719048	55000	0,000000803	0,2437	6
Methanol	0,043685714	1	0,04368571	55000	0,000000794	0,2411	7
Toluol	0,019314286	0,6	0,03219048	32500	0,000000594	0,1804	8
Acetone	0,080714286	0,35	0,23061224	150000	0,000000538	0,1633	9
Styrole	0,001557143	0,04	0,03892857	9500	0,000000164	0,0497	10
Xylol (sum)	0,003614286	0,2	0,01807143	50000	0,000000072	0,0219	11
…	…	…	…	…	…	…	…
Tribromomethane	0,000315714	0,05	0,00631429	172000	0,000000002	0,0006	17
Σ	0,272156214		2,48165832		0,000329473	100,0000	

The assessment of population health risk because of HS developed from vehicle traffic showed a high mathematical probability of a large number of extremely dangerous pathological effects occurrence (P_a> 0.7) (Table 3) based on computer simulations using the Prediction of Activity Spectra for Substances (PASS) program [12].

Table 3. Computer mode probabilities results of the pathophysiological effects influenced by xylol in the atmosphere surface layer of the roads (the fragment)

Pathophysiological effects (system damage probability)				
CNS	Respiratory system	Cardiovascular system, blood	Gastrointestinal tract	Cellular level
Xylol C_8H_{10}; Substance hazard category III; MAC =15 mg/m^3				
Convulsions (0,912); Euphoria (0,875); Demyelinization of the axons (0,859); Panic (0,844); Psychomotor disturbance (0,817); Extrapyramidal effects (0,789); Psychosis (0,720).	Respiration disturbance (0,828); Apnea (0,806); Respiratory depression (0,752).	Erythrocyte aplosia (0,867); Hidden bleeding (0,850); Atrial fibrillation (0,802); Hypotension (orthostatic) (0,789); Thrombocytopoesis block (0,773); Hypercholesterinemia (0,765); Hypochromic anaemia (0,760).	Black vomit (0,909); Aphthous ulcer (0,873); Gastrointestinal bleeding (0,842); Vomit (0,834).	Neutrophilous dermatosis (0,911); Fibrosis of the interstitial tissue (0,802);

Thus, an increased degree of toxic pollution from traffic flows creates real risks to population health living in the roadside area, which requires the use of corrective measures in environmentally unsafe areas of urban highways. In particular, using the algorithms and the program "Econavigator" developed by us (certificate on the state computer registration No. 2016663988), it is proposed to redistribute the movement of MVS in the most loaded parts of the SRN, directing them along alternative routes, which will reduce the concentration of HS in the surface layer of the atmosphere to a large extent (Figure 3).

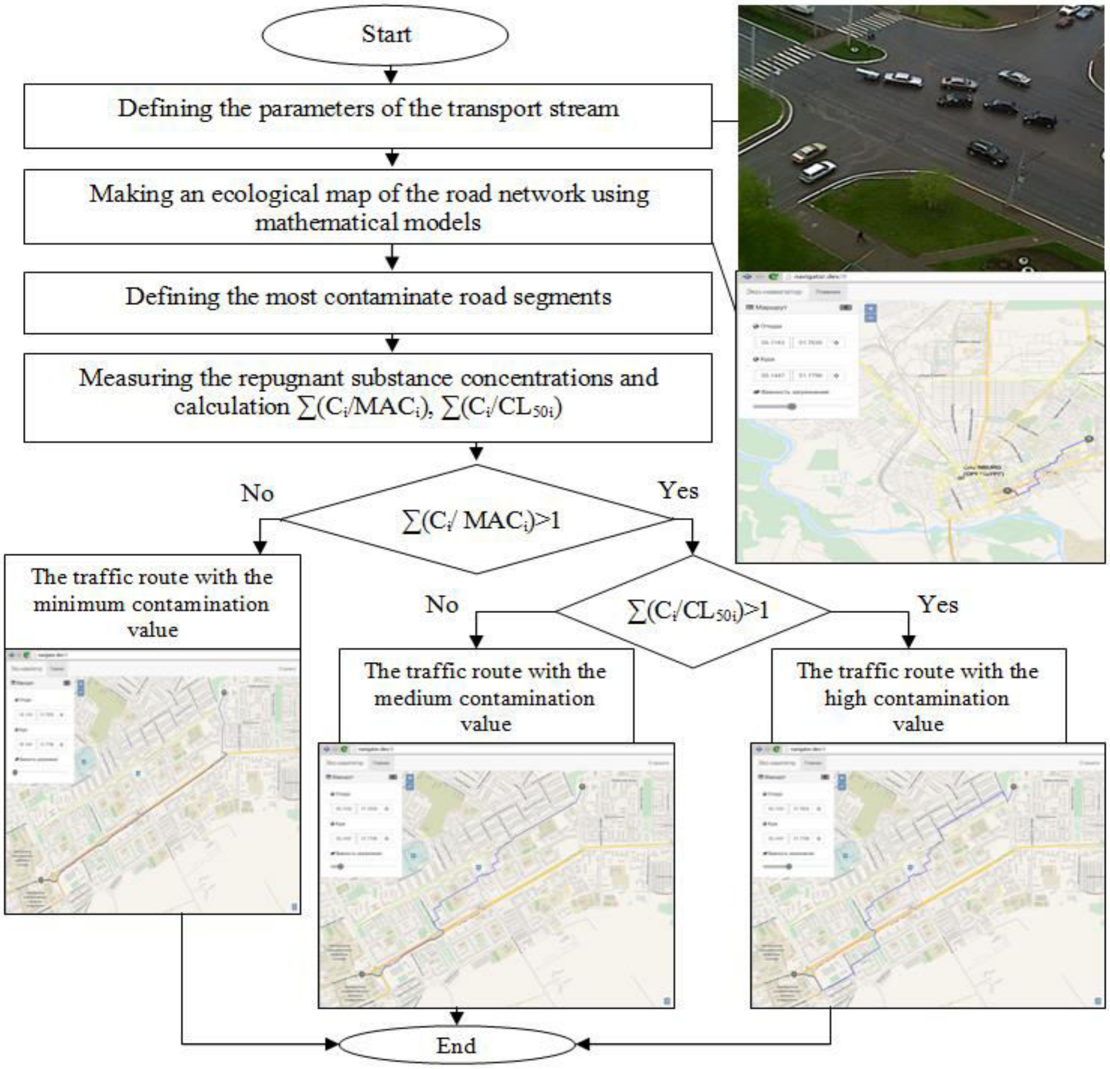

Fig. 3. Algorithm of the traffic route choice considering the atmosphere surface layer contamination by the transport streams

This program, taking into account the parameters of the traffic flow, makes it possible to build ecological maps of the city highways, which creates the prerequisites for the provision of quality maps in "real-time" mode. If necessary, the obtained quantitative information obtained on toxic substances for individual SRN can be detailed, for example, taking into account meteorological conditions.

CONCLUSIONS:

The application of the system approach to the assessment of motor transport flow ecological safety allows us to choose not only their optimal parameters, but also to estimate the total dose of toxicity of HS whole complex formed from EG, as the result of automobile tires, brake mechanisms and road surface wear. The most significant parameters of the traffic flow are established: composition, intensity, average speed and total volume of transport work during cargo-and-passenger transportation, expressed by us through the total weight of MVS in the traffic flow. A dose approach to the assessment of the entire complex toxicity of 17 HS in the most polluted areas of SRN made it possible to assess the degree of toxic pollution for the surface layer of the atmosphere within the motor roads in the districts of the city of Orenburg (total toxic dose makes 0.0003 on the average), and also to compile a rating series of substance danger. At that it was found that the greatest contribution to the total toxicity is made by benz(α)pyrene 68.65%, acrolein 19.73% and formaldehyde 7.81%. The indicator substances from HS complex are substantiated, taking into account their toxicity, recommended for environmental monitoring.

SUMMARY:

The results of environmental monitoring and simulation in the conditions of surface air pollution of motor roads with HS show the importance of optimal parameter justification for motor transport flows in the planning of cargo and passenger transportation taking into account their transportation work. The developed program "Econavigator" allows the drivers of MVS to choose the most environmentally friendly routes to bypass traffic jams and other parts of the SRN with difficult traffic due to the informing of road users about the degree of atmosphere surface layer pollution. The implementation of the proposed measures is aimed at the reduction of HS emission level from traffic flows and the reduction of their negative impact on the environment, which will minimize the risks of city population chronic diseases.

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