The object of this study is a regional center with a developed industry and a significant transport load. The study assesses the impact of car emissions on public health. It is shown that on average in the city, emissions from vehicles are 0.341 mg/m·s and vary from 0.038 to 1.012 mg/m·s. The main pollutants are nitrogen dioxide (from 39.3 to 58.5 % of the total emission, the average value is 50.9 %) and carbon monoxide (from 39.5 to 47.7 %, the average value is 38.7 %). There is an excess of the maximum permissible concentrations (MPC) by the content of NO_2 (1.5–4.5 MPC with an average value of 2.7 MPC), formaldehyde (4.3–4.4 MPC), hydrocarbons (1.2 MPC), soot (1.3 MPC). The level of carcinogenic danger for adults ($R=1.9\cdot10^{-4}$) and children ($R=3.8\cdot10^{-5}$–$9.8\cdot10^{-5}$) is rated as average. Soot (61.0 %) and formaldehyde (38.9 %) account for the largest contribution. Behind a non-carcinogenic risk, there is a significant danger of increasing morbidity of the population (HI=9.9–14.0 with an average value of 11.1). Principal pollutants are formaldehyde (37 %), NO_2 (23 %), hydrocarbons (17 %). The most vulnerable are the respiratory system (HI=8.7) and the immune system (HI=4.3). A significant health hazard is due to low fuel quality, technical and operational characteristics of cars, adverse natural conditions for the dispersion of impurities. The method of interpolation and extrapolation of the results of full-scale observations was used to assess the effect of gaseous and dust components from vehicles on humans. The current study makes it possible to assess the combined impact of pollutants on the risks of disease and premature death of the population, to identify the danger and zoning the territory by the level of danger. The results obtained can be important for making effective management decisions in the field of environmental protection and public health

Keywords: atmospheric air, road transport, emission of pollutants, risk to public health

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ASSESSING RISK CAUSED BY ATMOSPHERIC AIR POLLUTION FROM MOTOR VEHICLES TO THE HEALTH OF POPULATION IN URBANIZED AREAS

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1. Introduction

Air pollution, which is an important determinant of health, is one of the greatest environmental hazards faced by the world, especially children and older people [1]. In 2019, 99 % of the world's population lived in places where the level of air quality did not meet the requirements of the World Health Organization [2]. Air pollution in both urban and rural areas caused 4.2 million premature deaths worldwide in 2016 [3]. By 2050, premature mortality caused by poor air quality is projected to double. Despite the ongoing efforts of UN agencies and some national governments (mainly in high-income countries), there has been little real progress in tackling pollution. This is primarily due to the limited ability to conduct appropriate government policies in low- and middle-income countries where pollution is the highest [4]. The introduction of an effective government policy, a synergistic approach to achieve the Sustainable Development Goals will reduce the level of air pollution and the risk of disease and premature death of the population [5].

The greatest harm to health is caused by vehicles, the emissions of which are carried out at the respiratory level. Lung cancer, asthma, allergic diseases – all this is directly related to the discharge gases of vehicles. The gradual increase in cars in the context of global urbanization requires an integrated approach to solving the problem of air pollution and assessing the possible consequences for public health.

It should be noted that the pollution of rural areas with vehicle emissions is not fully understood, which is associated with both the multicomponent nature of their exhaust gases and the complexity of modeling the spread of impurities in the atmosphere. Health risk assessment depending on air quality can play a key role at the individual and global levels of health promotion and disease prevention.

Therefore, research aimed at studying environmental pollution and the following health effects is a relevant issue and needs to be studied.

2. Literature review and problem statement

Many papers report studies into the effect of atmospheric air quality on the danger to the population, indicating a noticeable undesirable both short-term and long-term impact of potentially toxic components of exhaust gases of cars on human health.

Study [6] found that the air pollutant with the widest list of health effects (about 30 diagnoses and causes of death) are particulate matter with a diameter of less than 2.5 micrometers (PM2.5). The regression model of particulate dispersion in the environment developed by the authors showed good results and can be applied to assess the chronic health consequences of PM2.5 long-term effects. However, to build the model, data from a short-term monitoring period and a limited number of pollutants were used, which can affect the accuracy of the results. In addition, meteorological conditions, which are important predictors of fluctuations in the concentrations of impurities, were not taken into account by the researchers.

Study [7] aims to assess the impact on public health of the concentration of solid particles PM2.5 that enter the atmospheric air from vehicles. To assess the risk, a model with a high spatial resolution at a distance of 1 km from the sources of influence was used. However, it is based on the results of modeling the qualitative and quantitative composition of the traffic flow and data from the National Emissions Inventory EPA, rather than full-scale observations. Accordingly, this model may not fully take into account higher car emissions when driving at low speeds and frequent stops in an overloaded urban center. In addition, the 1-kilometer resolution does not make it possible to cover microscale exposures near the highway, which can vary significantly within a few hundred meters of the road.

Paper [8] presents an approach based on a three-dimensional Euler-Lagrange dispersion model and data sampling using low-cost sensors to assess transport emissions. The proposed model demonstrates high reliability indicators of theoretical data and the possibility of their implementation in the applied aspect. However, the proposed model has a number of drawbacks, in particular, expensive software, the need for a large sample of data, inconsistencies in time information, which can cause errors in the forecasting process. The method uses only the average annual concentration field as spatial a priori information. The accuracy of the method clearly depends on the accuracy of the available input data.

In [9], a model based on the multiple regression algorithm has been developed, which makes it possible to predict the concentration of dust particles PM10. Their results showed good consistency between the predicted and actual values but this model lacks spatial information.

Paper [10] investigated the association of concentrations of PM10 and PM 2.5 with health risk using the standard time series approach. The analysis included 24 major countries and regions on six continents in 652 cities. In such a global study that spanned several decades, diagnostic errors or the coding of health data are inevitable. The authors used the results of stationary measurements of impurity concentrations, which could also lead to an incorrect classification of the impact.

Paper [11] investigated the long-term effects on human health of a wider range of pollutants, in particular benzene, carbon monoxide, nitrogen dioxide, sulfur dioxide, and solid particles PM10 and PM2.5. For the analysis, data from air quality monitoring stations were used. However, when describing the general trend of changing pollution levels, the authors did not take into account local atmospheric and topographic conditions.

It should be noted that in many studies the assessment of the effect of polluted atmospheric air on public health was carried out for large cities and industrial centers. Only in a small part of works, attention is paid to this issue for small settlements. This makes it difficult to extrapolate the results of monitoring data and make effective management decisions to reduce the risk to public health. Therefore, research related to the assessment of the risk to public health from motor transport in cities requires further development.

3. The aim and objectives of the study

The aim of this work is to quantify the risk to public health from vehicle emissions in a city with developed industry and significant traffic load. This will provide important information to manage risk and reduce the health hazards of city residents.

To accomplish the aim, the following tasks have been set:

– to assess the qualitative and quantitative composition of traffic flows on the main highways of Cherkasy;

– to calculate the emission of the main pollutants from vehicles;

– to calculate the concentration of impurities in the atmospheric air of the suburban strips;

– to assess the carcinogenic and non-carcinogenic risk to public health from road transport emissions.

4. The study materials and methods

As an object of assessing the impact of traffic flows on the level of danger to public health, the city of Cherkasy was chosen – a regional center with a developed industry and a significant transport load. The territory of the city is a wavy plain with a dominant surface slope of 2–5 %. The population is 270 thousand people. The H-16 national highway and the R-10 regional road pass through the city. Emissions of mobile sources in the city are at the level of 50–75 % of the total emissions in the city, the share of vehicles in them is 90–95 %.

To calculate emissions from vehicles, an assessment of the quantitative and qualitative composition of traffic flows on the highways of the city was carried out. For the study, 25 sites passing through rural and industrial zones with different levels of transport load, different density, and height of development were selected (Fig. 1). Full-scale observations of the intensity of traffic were carried out on weekdays and on weekends during the hours of the greatest load. Separately, we counted cars, vans, medium trucks, heavy trucks, and buses.

To determine the amount of emission of pollutants from cars (carbon oxide, nitrogen oxides NO_x (in terms of nitrogen dioxide), CH hydrocarbons, soot, sulfur dioxide SO_2, formaldehyde CH_2O, benzopyrene $C_{20}H_{12}$), we used the procedure from [12].

To simulate air quality, an interpolation model of the Gaussian dispersion of impurities in atmospheric air was used. The European Environmental Protection Agency has collected more than 150 different models that allow us to predict the spread of impurities by interpolation and extrapolation of measured data. Most models are based on the theory of atmospheric diffusion of pollutants [13–15] and empirical-statistical analysis of the distribution of impurities using Gaussian interpolation models [16–18]. Gaussian models have been most widely used because of the simplicity and high accuracy of the calculation in the presence of minimal information about the state of the surface layer of the atmosphere.

Fig. 1. Map of the location of the study sites

The concentration of toxic components of the car's exhaust gases in the air (in g/m^3) was calculated according to the formula:

$$C_i = \frac{2 \cdot q_i}{\sqrt{2 \cdot \pi} \cdot \sigma \cdot V \cdot \sin\phi} + F, \quad (1)$$

where q_i – the emission of a certain substance, g/m·s;

σ – standard deviation of the Gaussian distribution in the vertical direction, m;

V – wind speed, m/s;

F – background concentration of toxic component, g/m^3;

φ – the angle that makes up the direction of the wind with the direction of movement of the traffic flow.

To calculate the concentration of pollutants, the average annual indicators of meteorological conditions (wind speed and direction) and background concentrations at observation posts corresponding to the location of the model sites were used.

The risk to public health was assessed by the procedure from [19], which was developed according to the original methodology of the US EPA [20]. Based on this methodology, it is possible to both identify and quantify the risk and manage the danger.

Analysis of the information received and its visualization was carried out using Golden Software Surfer (USA) software [21].

5. Results of studies of the risk to public health from vehicle emissions in urbanized areas

5. 1. The results of the assessment of the qualitative and quantitative composition of traffic flows

The basis of the transport system of Cherkasy is the existing main street network. The main types of vehicles are cars and trucks, public buses and taxis (city route and private), trolleybuses. A significant share of the fleet is used cars. The average age of a passenger public fleet is more than 20 years and is updated very slowly. Almost 90 % of the fleet of buses and fixed-route taxis has already exceeded their maximum service life.

The number of vehicles registered in the city: buses – 1846 units, trucks – 13974 units, cars – 64685. Bus passenger transportation provides 275 units of rolling stock. The total length of the transport network along the axis of streets within the city is 486.2 km.

Full-scale observations of the structure of traffic flows carried out during 2021 (Fig. 2) showed the dominance of passenger vehicles, the share of which was 58–95 % of the total number of cars.

The number of cars in different areas ranged from 228 to 1287 units per hour with an average number of 770 units in the city.

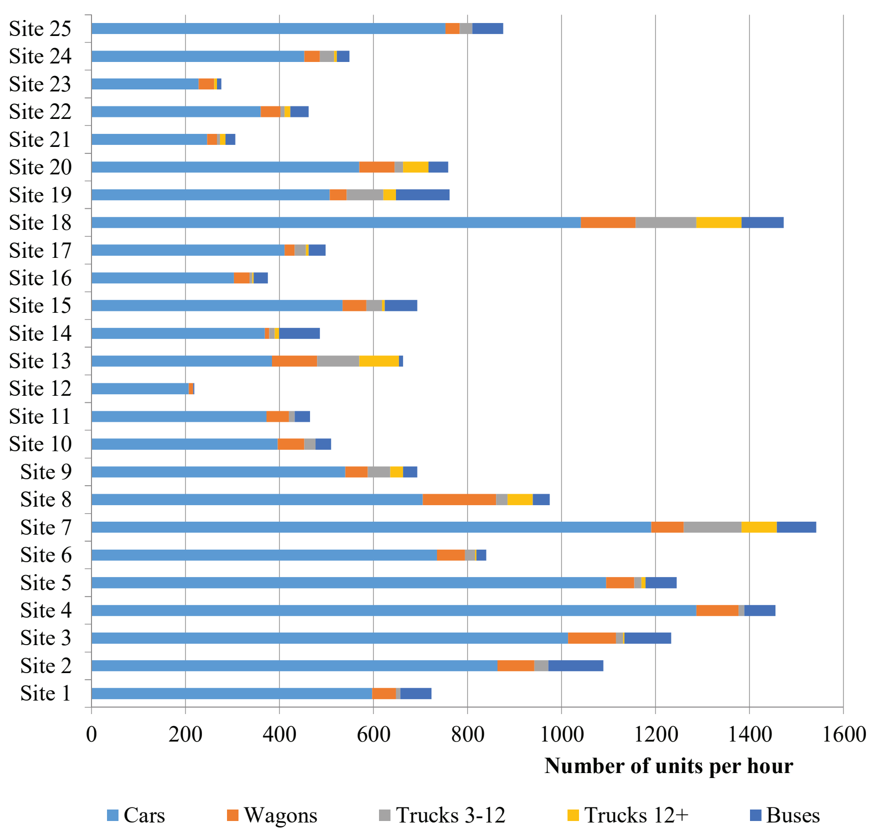

Fig. 2. Traffic flow structure

5. 2. Results of the calculation of the emission of pollutants from vehicles

The city has a strong transport infrastructure, but transport interchanges do not correspond to the existing traffic flows, especially in the city center. Most of the car fleet is old, almost half of it are cars of the environmental standard EURO-0.

This is an important aspect because the qualitative and quantitative composition of exhaust gases depends on the technical condition of cars and the conditions of movement of the traffic flow, the quality of fuel, and the technologies used to reduce emissions.

According to the results of the study, the total emission of pollutants was 0.341 mg/m·s and in different areas it varied from 0.038 to 1.012 mg/m·s (Table 1)

Table 1

Emission of pollutants with exhaust gases of cars, mg/m·s

Site No.	CO	NO_2	CH	Soot	SO_2	H_2CO	$C_{20}H_{12}$
1	0.063	0.078	0.013	0.001	0.0003	7.4E-05	8.1E-09
2	0.120	0.164	0.027	0.003	0.0005	1.4E-04	1.5E-08
3	0.154	0.185	0.033	0.003	0.0007	1.8E-04	1.9E-08
4	0.148	0.154	0.035	0.002	0.0008	1.9E-04	2.1E-08
5	0.092	0.106	0.020	0.002	0.0005	1.2E-04	1.3E-08
6	0.072	0.076	0.018	0.001	0.0004	9.2E-05	1.0E-08
7	0.311	0.504	0.083	0.011	0.0017	4.0E-04	4.2E-08
8	0.187	0.242	0.043	0.005	0.0009	2.1E-04	2.1E-08
9	0.050	0.077	0.014	0.002	0.0003	6.5E-05	6.7E-09
10	0.056	0.070	0.013	0.001	0.0003	6.2E-05	6.6E-09
11	0.058	0.068	0.013	0.001	0.0003	6.4E-05	6.9E-09
12	0.020	0.016	0.005	0.000	0.0001	2.5E-05	3.0E-09
13	0.149	0.260	0.040	0.006	0.0008	1.8E-04	1.7E-08
14	0.076	0.125	0.017	0.002	0.0003	8.3E-05	9.0E-09
15	0.130	0.182	0.030	0.003	0.0006	1.5E-04	1.5E-08
16	0.058	0.071	0.013	0.001	0.0003	6.5E-05	7.1E-09
17	0.090	0.128	0.022	0.002	0.0005	1.1E-04	1.2E-08
18	0.240	0.400	0.061	0.009	0.0012	2.9E-04	2.9E-08
19	0.330	0.592	0.080	0.012	0.0014	3.8E-04	3.8E-08
20	0.311	0.450	0.077	0.009	0.0016	3.6E-04	3.8E-08
21	0.128	0.172	0.029	0.003	0.0007	1.5E-04	1.6E-08
22	0.100	0.133	0.022	0.002	0.0005	1.1E-04	1.2E-08
23	0.036	0.038	0.009	0.001	0.0002	4.1E-05	4.5E-09
24	0.080	0.100	0.020	0.002	0.0004	9.8E-05	1.1E-08
25	0.105	0.138	0.024	0.002	0.0006	1.3E-04	1.5E-08

The main pollutants emitted by road are nitrogen dioxide (52.9 % of the total emission), carbon oxide (36.9 %), and hydrocarbons (8.9 %). The share of soot, sulfur dioxide, formaldehyde, and benzopyrene accounts for 1.2 %.

5. 3. Results of the calculation of the concentration of impurities in the atmospheric air of the subtract lanes

The dispersion of exhaust gases of vehicles in cities is different from the scattering in open areas. The intensity of vertical and horizontal turbulence, which affects the fluctuations of concentrations, is limited in rural areas with dense high-rise buildings. This causes differences in the formation of the level of air pollution.

It should also be noted that the city of Cherkasy has unfavorable natural conditions for the dispersion of impurities, in particular, a significant repeatability of weak winds throughout the year and frequent ground inversions. The territory of the city belongs to the zone of very high potential of pollution (meteorological potential 3.4), the processes of air pollution prevail over its ability to self-purification.

The calculated concentrations of impurities in atmospheric air, according to the interpolation Gaussian model, showed a high content of formaldehyde, NO_2, hydrocarbons, and soot (Table 2).

Table 2

Concentrations of impurities in the atmospheric air of near-motorway lanes, units MPC

Site No.	CO	NO_2	CH	Soot	SO_2	H_2CO	$C_{20}H_{12}$
1	0.67	2.21	1.33	1.20	0.40	4.34	0.40
2	0.67	2.81	1.34	1.21	0.40	4.34	0.40
3	0.68	3.17	1.34	1.21	0.40	4.35	0.40
4	0.68	3.01	1.34	1.21	0.40	4.35	0.40
5	0.67	2.77	1.34	1.21	0.40	4.34	0.40
6	0.67	2.44	1.33	1.20	0.40	4.34	0.40
7	0.69	4.51	1.34	1.24	0.41	4.36	0.41
8	0.68	2.94	1.34	1.21	0.40	4.34	0.40
9	0.67	2.22	1.33	1.20	0.40	4.34	0.40
10	0.67	2.60	1.33	1.20	0.40	4.34	0.40
11	0.67	2.59	1.34	1.20	0.40	4.34	0.40
12	0.67	2.32	1.33	1.20	0.40	4.34	0.40
13	0.67	2.74	1.34	1.21	0.40	4.34	0.40
14	0.67	2.36	1.33	1.20	0.40	4.34	0.40
15	0.67	2.52	1.34	1.21	0.40	4.34	0.40
16	0.67	2.60	1.34	1.20	0.40	4.34	0.40
17	0.67	2.88	1.34	1.21	0.40	4.34	0.40
18	0.68	3.96	1.34	1.24	0.40	4.35	0.41
19	0.69	4.20	1.34	1.25	0.41	4.36	0.41
20	0.69	3.48	1.34	1.24	0.41	4.36	0.41
21	0.67	2.11	1.34	1.21	0.40	4.34	0.40
22	0.67	1.92	1.34	1.21	0.40	4.34	0.40
23	0.67	2.18	1.33	1.20	0.40	4.34	0.40
24	0.67	1.51	1.33	1.20	0.40	4.34	0.40
25	0.67	2.67	1.34	1.21	0.40	4.34	0.40

The greatest spatial variability of concentrations was found for NO_2, which is explained by differences in background concentrations that are taken into account in the Gaussian model (1). According to the Cherkassy Hydrometeorological Center, the background concentrations of this pollutant differ in different parts of the city almost twice, which affects the level of air pollution with nitrogen dioxide in different areas. The multiplicity of excess MPC varied from 1.5 to 4.5 with an average value in the city of 2.7. The greatest concentrations are at sites 7 (4.5 MPC), 19 (4.2 MPC), 18 (4.0 MPC), and in the central part of the city – 2.8–3.0 MPC (Table 2, Fig. 3).

The levels of air pollution of the near-motorway lanes with other impurities, which have the same values of background concentrations throughout the city, are characterized by greater homogeneity. According to the content of formaldehyde, a high level of pollution is predicted (4.3–4.4 MPC). The concentrations of hydrocarbons and soot are 1.2 MPC and 1.3 MPC, respectively. According to sulfur dioxide, carbon monoxide, and benzopyrene, no excess of standard values is predicted.

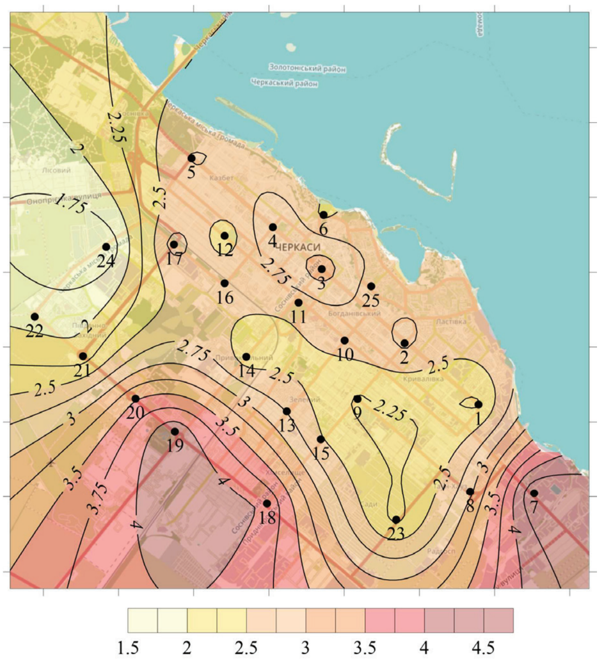

Fig. 3. The map scheme of zoning the city territory by the level of air pollution with nitrogen dioxide

5. 4. Results of public health risk assessment

Excessive air pollution of roadside areas with emissions can have a significant impact on the health of the city's population.

The assessment of non-carcinogenic risk showed that with the projected level of air pollution of roadside areas there is an extremely high risk of increasing morbidity of the population (HI=9.9–14.0 with an average value of 11.8) (Table 3, Fig. 4). According to the international classification, the coefficients and hazard indices of non-carcinogenic risk greater than 1 indicate the likelihood of harmful effects in the organs and systems of the human body, which increases in proportion to their increase.

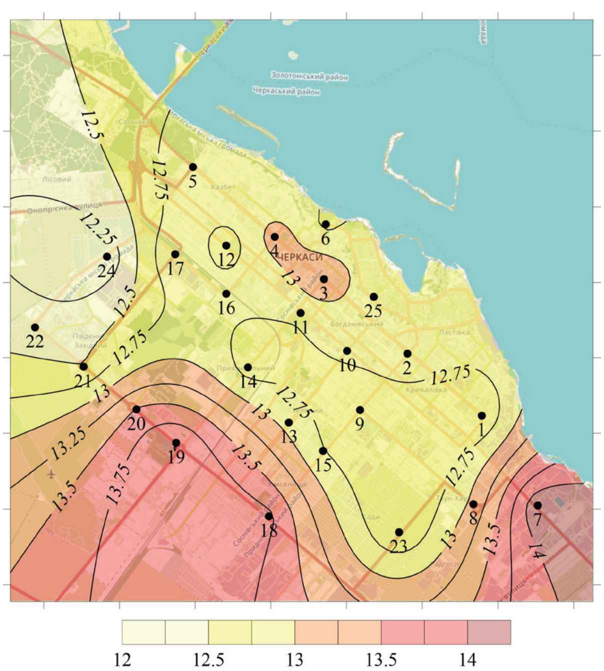

Fig. 4. The map scheme of zoning the territory of Cherkassy by total non-carcinogenic risk

According to the identified quantitative and qualitative composition of air pollution of near-motorway lanes, the most vulnerable are the respiratory system (*HI*=8.7) and the immune system (*HI*=4.3) (Table 3, Fig. 5).

Fig. 5. The map scheme of zoning the territory of the city of Cherkasy by the risk of developing respiratory diseases

The greatest danger of non-carcinogenic risk comes from formaldehyde (37 %), nitrogen dioxide (23 %), and hydrocarbons (17 %) (Fig. 6, 7).

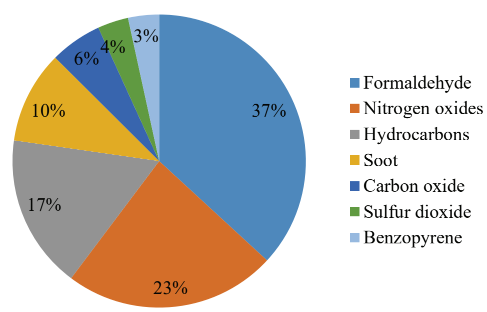

Fig. 6. The share of pollutants in the development of harmful effects in the organs and systems of the human body

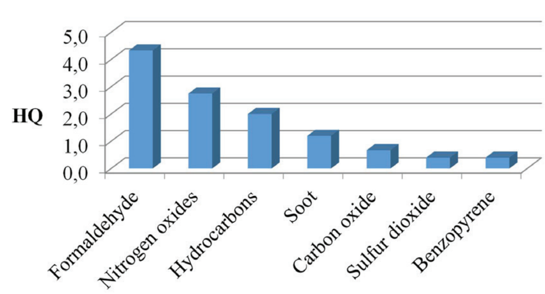

Fig. 7. Ranking of substances by non-carcinogenic risk to public health

The influence of environmental factors also predetermines the possibility of malignant neoplasms. In determining the probable individual carcinogenic risk, the concentrations of formaldehyde, soot, and benzopyrene were taken into account. It turned out that there is a risk of getting cancer for both adults (R=1.9·10^{-4}) and children (R=9.8·10^{-5}). According to the classification of the US Environmental Protection Agency, it can be estimated as average. The main contribution to the risk of developing cancer is introduced by soot (61 %) and formaldehyde (38.9 %).

6. Discussion of results of the study of assessing the risk to public health from air pollution by road vehicles

Our studies of the qualitative and quantitative composition of the traffic flow showed significant differences at different sites (Fig. 2). The share of passenger vehicles was 58–95 % of the total number of cars, heavy vehicles – on average 6–7 % and in different areas varied from 0 to 14 %, the number of vans and buses – on average 9 and 10 %, respectively. The highest activity of freight traffic of both categories was recorded at sites 13 (27 %), 18 (16 %), 19 (14 %), and 7 (13 %). The density of the traffic flow is the highest at sites 7 (1542 units/h), 4 (1473 units/h), and 18 (1455 units/hour).

Differences in the structure of the traffic flow led to a different projected amount of emissions in the studied territories. The largest emission of pollutants (Table 1) is at sites 19 (1.01 mg/m·s), 7 (0.91 mg/m·s), and 18 (0.70 mg/m·s). They have more heavy vehicles in the structure of the traffic flow compared to other sites (Fig. 2). For these vehicles, the specific emissions of pollutants are the highest, especially in comparison with passenger cars. In particular, in terms of soot, NO_2, hydrocarbons, and formaldehyde, these figures are 80, 23, 8, and 6 times larger, respectively.

Modeling the distribution of impurities in the atmosphere based on the Gaussian simulation model showed that formaldehyde, NO_2, hydrocarbons, and soot pose the greatest danger in the formation of a high level of pollution (Table 2).

According to the content of formaldehyde, the multiplicity of excess of the average daily MPC in all areas is 4.3–4.4. The obtained forecast values of the level of air pollution of the near-motorway lanes are generally consistent with the results of formaldehyde concentrations measured in previous studies on highways with a similar composition of traffic flows [22]. So, the Gaussian model used quite accurately describes the spread of impurities in the atmosphere.

According to the content of NO_2, the multiplicity of excess of the MPC is 1.5–4.5 with an average value of 2.7 (Table 2). According to the map scheme (Fig. 3), created using the Golden Software Surfer software package, the main pollution zones are formed at sites 7 (4.5 MPC), 19 (4.2 MPC), and 18 (4.0 MPC). This is due to the greater number of medium and heavy vehicles on them. This territory belongs to the mixed industrial-rural zone. In the central part of the city with dense high-rise buildings, the excess of the normative values of the concentration of NO_2 is 2.8–3.0 MPC.

The population living near highways is exposed to the high concentrations of pollutants contained in the exhaust gases of cars. The presence of people for a long time in such dangerous conditions weakens the immune system of the human body and leads to the development of various diseases. An assessment of the risk to public health of motor vehicle emissions conducted using the US EPA methodology showed that residents of the city are experiencing significant anthropogenic pressure. According to the total non-carcinogenic risk, there is a high risk (HI=9.9–14.0) of an increase in the incidence of chronic diseases (Table 3, Fig. 4). The most vulnerable are the respiratory system (HI=8,7) and the immune system (HI=4,3) (Table 3, Fig. 5). The risk of developing diseases of the central nervous system and blood is estimated as medium, cardiovascular – low.

Ranking of substances by non-carcinogenic risk showed that the main danger is emissions of formaldehyde (37 %), nitrogen dioxide (23 %), and hydrocarbons (17 %) (Fig. 6, 7). The most dangerous situation is in the microdistricts of Dniprovskyi, Khimselishche, and in the area of Victory Park (Fig. 4, 5), which correlates with the intensity and composition of the traffic flow in these territories (Fig. 2) and levels of air pollution (Fig. 3).

The high level of air pollution causes a risk for city residents to get sick with cancer. The level of individual carcinogenic risk for adults (R=1.9·10^{-4}) and children (R=9.8·10^{-5}) is estimated as average. Dynamic control and in-depth study of the sources and possible consequences of harmful effects are needed to make effective management decisions to reduce risk.

Soot (61.0 %) and formaldehyde (38.9 %) have the greatest contribution to overall carcinogenic risk. Over the past 5 years, the city has seen an increase in the concentration of formaldehyde by 1.5 times. Taking into account the tendency to increase the concentration of this toxic gas and the high content of nitrogen dioxide, which is a modifier of carcinogenesis, careful monitoring of the level of air pollution is necessary.

It should be noted that according to statistics, the general pattern for Cherkasy is the dominance over other classes of respiratory diseases – 58 %. The prevalence of colds among the population living in the Khimselishche area is twice as high as in other areas of the city, which is presumably associated with low immunity. In the structure of total mortality, the first place is occupied by diseases of the circulatory system (59.1 %), the second – neoplasms (18.8 %).

Consequently, the population living in the zone of influence of roads with heavy traffic has a risk of poor health due to the pathology of the respiratory systems and cancer diseases. Identifying high-risk areas provides important information for managing risk and reducing the health hazards of city residents.

In contrast to studies [6–10] where a limited number of pollutants were considered, our results make it possible to more accurately assess the combined effect of pollutants from vehicles on health risks, as well as to identify the most dangerous areas of the city.

The disadvantages of the study are the uncertainty of the impact on the level of expected risk to public health of seasonal fluctuations in meteorological conditions and distance from the highway. But this went beyond the scope of the study and may be the topic of future studies.

This study has some limitations. The accuracy of the risk assessment is largely based on the availability of key information about the characteristics of pollutants. There are no established values for all parameters that are used in risk assessment formulas. In particular, the carcinogenic potential factor, reference dose, critical organs and systems are periodically refined and updated. As a result, the values that will be chosen by the authors in other studies may lead to other estimates. Differences in the results may also be due to the peculiarities of the study areas (relief, meteorological conditions for the dispersion of impurities), traffic intensity, technical and operational characteristics of vehicles and their compliance with modern environmental standards.

Our results, from the assessment of the impact of vehicle emissions on health, can be important for making effective management decisions in the field of environmental protection and public health. Annual control and in-depth study of the sources of pollution and the possible consequences of their harmful effects is necessary. The introduction of a transport and environmental monitoring system, the transition to electric transport, cleaner heavy diesel vehicles, and low-emission vehicles will reduce the risk from air pollution and the incidence rate of the population.

7. Conclusions

1. The traffic flow on the highways of the city is characterized by the dominance of passenger vehicles, the share of which is 58–95 % of the total number of cars, and a significant diversity in both quantitative and qualitative composition. The differences are due to the complex planning structure of the city and the degree of development of transport infrastructure.

2. On average, in the city, the emission of pollutants from vehicles is 0.341 mg/m·s and varies from 0.038 to 1.012 mg/m·s. Significant variability of emission is due to the structure of the traffic flow, the technical and operational characteristics of cars, the state of transport infrastructure. The main pollutants are nitrogen dioxide (39.3–58.5 % of total emission, average value – 50.9 %) and carbon oxide (39.5–47.7 %, average value – 38.7 %).

3. The greatest danger of forming a high level of air pollution in roadside areas comes from formaldehyde, NO_2, hydrocarbons, and soot. There is an excess of the maximum permissible concentrations according to the content of NO_2 (1.5–4.5 MPC with an average value of 2.7 MPC), formaldehyde (4.3–4.4 MPC), hydrocarbons (1.2 MPC), soot (1.3 MPC). Significant pollution of residential areas is caused by the peculiarities of dispersion in conditions of dense high-rise buildings, adverse meteorological conditions.

4. Polluted air poses a threat to the health of city residents. The level of carcinogenic risk for adults (R=1.9·10^{-4}) and children (R=3.8·10^{-5}–9.8·10^{-5}) is estimated as average. Soot (61.0 %) and formaldehyde (38.9 %) introduce the greatest contribution. Behind the non-carcinogenic risk, there is a significant risk of increasing morbidity of the population (HI=9.9–14.0 with an average value of 11.1). Priority pollutants are formaldehyde (37 %), NO_2 (23 %), hydrocarbons (17 %). The most vulnerable are the respiratory system (HI=8,7) and the immune system (HI=4,3).

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

The data will be provided upon reasonable request.

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