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Assessment of environmental risks from atmospheric air pollution in industrially developed regions of Ukraine

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Abstract. Currently, atmospheric pollution is one of the main causes of premature mortality in the world. The problem is especially relevant for economically underdeveloped countries, in particular Ukraine, the economy of which has been developing for a long time in an extensive way. The complicated socio-ecological situation in the territory of the country

is due, first of all, to insufficient financing of the medical industry and environmental protection, outdated technologies in industries, etc. The purpose of the study is to assess the environmental risks of atmospheric air pollution in industrialized regions of Ukraine. Kharkiv and Dnipro regions, which are part of the Donetsk-Prydnistrovsky economic macro-district, a powerful center of metallurgy and machine-building of the national level, were selected for the study. As part of the study, the ambient air condition was assessed from the point of view of sanitary-hygienic norms in compliance with state environmental standards as well as the risks of carcinogenic and non-carcinogenic effects from atmospheric pollution. Regional monitoring data on average annual concentrations of common pollutants and heavy metals in the atmospheric air of the cities of Kharkiv and Dnipro regions were used in calculations, averaged over the period from 2014 to 2016. The results of calculations have shown that the total non-carcinogenic risk from atmospheric air pollution in all studied cities exceeds the permissible level: Dnipro – 19.8 HQ; Kamianske – 23.3 HQ; Kryviy Rig – 19.3 HQ; Kharkiv – 11.9 HQ. The pollutants: PM_{2.5}, copper, formaldehyde, nitrogen dioxide, manganese and phenol mostly contribute to the greatest non-carcinogenic risk. The dominance of these chemicals and elements in the structure of pollution in the studied cities leads to high probability of development of harmful effects in the respiratory organs – 11.1 to 22.3 HQ; cardiovascular system – 2.9 to 12.3 HQ; immune system – 1.7 to 4.7 HQ; eyes – 0.8 to 4 HQ; central nervous system – 1.4 to 4.6 HQ. The risk of carcinogenic effects is calculated for substances with proven carcinogenic effects: formaldehyde, nickel, cadmium, lead and chromium. The obtained carcinogenic risk from atmospheric air pollution within the studied cities falls into two categories: conventionally acceptable level of risk and acceptable level of risk. The greatest carcinogenic danger is from pollution of atmospheric air by chromium. Contribution of chromium to total carcinogenic risk ranges from 53.6 to 90.6%. Taking into account the obtained results, it is expedient to include the assessment of the risks to the population's health in the system of monitoring and control of the environment in Ukraine.

Keywords: environmental safety, population health, heavy metals, atmospheric air, carcinogenic risk, non-carcinogenic risk

Оцінка екологічних ризиків від забруднення атмосферного повітря у промислово розвинених регіонах України

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Анотація. Сьогодні забруднення атмосфери належить до головних причин передчасної смертності у світі. Особливо актуальною проблема є для економічно слабозрозвинених країн, зокрема України, економіка якої тривалий час розвивалась екстенсивним шляхом. Складна соціально-екологічна ситуація на території держави обумовлена, насамперед, недостатнім фінансуванням медичної галузі і охорони довкілля, наявністю застарілих технологій на виробництвах тощо. Мета дослідження – оцінка екологічних ризиків від забруднення атмосферного повітря у промислово розвинених регіонах України. Для дослідження обрано Харківську і Дніпропетровську області України, які входять до складу Донецько-Придніпровського економічного макрорайону – потужного центра металургії і машинобудування національного рівня. У рамках дослідження проведено санітарно-гігієнічну оцінку стану атмосферного повітря на відповідність державним екологічним нормативам, оцінку ризиків розвитку канцерогенних і неканцерогенних ефектів від забруднення атмосферного повітря. При виконанні розрахунків

використані дані регіонального моніторингу щодо середньорічних концентрацій загальнопоширених забруднюючих речовин і важких металів в атмосферному повітрі міст Харківської і Дніпропетровської областей, усереднені за період із 2014 по 2016 рік. Результати розрахунків показали, що сумарний неканцерогенний ризик від забруднення атмосферного повітря в усіх досліджуваних містах перевищує допустимий рівень: м. Дніпро – 19,8 HQ; м. Кам'янське – 23,3 HQ; м. Кривий Ріг – 19,3 HQ; м. Харків – 11,9 HQ. Найбільший внесок у сумарний неканцерогенний ризик вносять такі поллютанти: пил, мідь, формальдегід, діоксид азоту, марганець і фенол. Домінування зазначених хімічних речовин та елементів у структурі забруднення обумовлює для населення досліджуваних міст високу імовірність розвитку шкідливих ефектів в органах дихання – від 11,1 до 22,3 HQ; серцево-судинній системі – від 2,9 до 12,3 HQ; імунній системі – від 1,7 до 4,7 HQ; очах – від 0,8 до 4 HQ; ЦНС – від 1,4 до 4,6 HQ. Ризик розвитку канцерогенних ефектів розраховано для речовин із доведеною канцерогенною дією: формальдегід, нікель, кадмій, свинець та хром. Отримані значення канцерогенного ризику від забруднення атмосферного повітря у межах досліджуваних міст належать до двох категорій: умовно прийнятний рівень ризику і прийнятний рівень ризику. Найбільшу канцерогенну небезпеку представляє забруднення атмосферного повітря хромом. Внесок хрому у значення сумарного канцерогенного ризику складає від 53,6 до 90,6 %. Враховуючи отримані результати, доцільним є включення оцінки ризиків для здоров'я населення до системи моніторингу і контролю за станом довкілля в Україні.

Ключові слова: екологічна безпека, здоров'я населення, важкі метали, атмосферне повітря, канцерогенний ризик, неканцерогенний ризик

Introduction. Intensification of processes of technogenesis in the 20th century has caused contamination of the components of the environment, which in some territories reached critical levels for people's life and health. In particular, in London in 1952 atmospheric air pollution combined with temperature inversion led to the formation of a powerful smog, which, according to various estimates, killed about 12,000 people (Bell, Davis, & Fletcher, 2004). A similar case with fewer victims occurred earlier in Belgium in 1930. At that time, smog with an increased content of sulfur dioxide caused premature deaths of more than 60 people.

Awareness of the catastrophic consequences of the disruption of the ecosystem balance prompted national governments to legislatively approve acceptable levels of environmental pollution. However, the establishment of environmental restrictions have far from entirely succeeded in getting rid of the effects of negative technogenesis on human life and health. According to Landrigan et al., 2017, due to diseases caused by environmental pollution 9 million people died prematurely in the world in 2015. This includes 6.5 million people who died from the pollution of atmospheric air, clearly the greatest source of danger.

Environmental problems for countries with low and average income levels, where the death rate due to environmental pollution is 92% of the global indicator, are particularly relevant today (Landrigan et al., 2017). The complicated environmental situation is usually caused by the industrialized economy, a high proportion of energy-intensive and material-intensive industries, outdated technologies, insufficient expenditures on environmental protection needs and on medicine, and so on. Taking the above into account, there is a need for research in the field of environmental safety assessment of such regions with regard to human life.

Analysis of recent research and publications.

Analysis of present-day research in the field of environmental safety indicates the priority of the problem of air pollution in most regions of the world. In the United States alone, changes in the concentration of PM_{2.5} in the surface layer of the atmosphere annually lead to 200,000 premature deaths, in O³–to 10,000 premature deaths (Caiazzo, Ashoklan, Waitz, Yim, & Barrett, 2013). In China, between 2004 and 2012, the number of premature deaths from atmospheric PM_{2.5} increased from 0.8 to 1.2 million per year (Liu et al., 2017). The economic loss from the negative impact of atmospheric air pollution on health in Europe and the United States is estimated at 300 and 145 billion euros, respectively (Im et al., 2018).

Particular attention in modern studies is devoted to the influence of meteorological conditions on the quality of atmospheric air. The authors (Revich et al., 2015) determined the dependence of mortality increases of 0.47 and 0.41% on an increase in daily average concentrations of PM₁₀ and O³ by 10 µg/m³, respectively, during the period of abnormal heat in Moscow. Research results (Wang, Chen, & Liu, 2015), conducted in China indicated a positive correlation between the reduction of the Arctic sea ice area and the increase in the number of foggy days in the country. Taking into account further reduction of the ice cover due to global warming [Maksymenko, Medvedeva, & Cherkashyna, 2019], a tendency to increase in the number of days with favourable conditions for the formation of smogs becomes a significant factor in increasing the level of environmental hazard in the region.

A significant number of Ukrainian scientists are devoting their research to the problems of regionalization and spatio-temporal structuring of environmental hazards, and selection of criteria for the establishment of danger levels, etc. In particular,

in the work (Yatsenko & Ivaniuta, 2013) it is proposed to add the indicator of density of the common pollutants' emissions per unit area or per capita to the normative indicators of the air quality assessment. A similar approach is used by the authors (Ivaniuta & Kachynskiy, 2013) when ranking the administrative regions of Ukraine on the basis of pollutant emissions per capita. It is carried out in relation to the administrative area with the highest value of the indicator adopted for 1. The assessment methodology of the condition and development of the regions by the ITSEEDI index is developing, allowing one to consider the connection between the subsystems of the environment based on the integrated approach (Nekos & Soloshych, 2014).

An overview of recent studies in the field of environmental safety of the regions of Ukraine shows that the problem of excesses over sanitary and hygiene standards receives the bulk of attention. This approach does not allow to take into account the physiology of the cohort, the quantification of the probability of diseases and mortality among the population, or attempt to determine the critical organs and systems of the human body, subject to the exposure to certain pollutants. Considering the above, it is expedient to assess environmental safety, including safety of atmospheric air, as a criterion for the health risks of the population.

The purpose of the work is to assess the environmental risks of atmospheric air pollution in industrialized regions of Ukraine.

Materials and methods of research. During the study, the materials of "Regional reports on the state of the environment" in Kharkiv and Dnipropetrovsk regions of Ukraine for the period from 2014 to 2016 were used, namely, the data of average annual content of pollutants in the atmospheric air of the following cities: Kharkiv, Dnipro, Kryvy Rih and Kamianske. The materials used are official public open access data. The monitoring of atmospheric air is carried out on a regular basis by the regional subdivisions of the Ministry of Ecology and Natural Resources of Ukraine.

Assessment of the dangers of atmospheric air pollution for the health of the population was carried out according to the risk criterion for the development of carcinogenic and non-carcinogenic effects according to the methodology (Rukovodstvo po ocnke rizika dlja zdorov'ja naselenija pri vozdeystvii himicheskikh veshhestv, zagrijaznjajushhiih okruzhajushhuju sredu, 2004). Carcinogenic risk is calculated according to formulae 1.1 and 1.2. In assessing carcinogenic risk, standard values of exposure were used: human weight – 70 kg, period of exposure averaging and duration of

exposure – 70 years, the volume of atmospheric air entering the human body – 20 m³/day.

$$CR = LADD \cdot SF, \quad (1.1)$$

where

CR – individual carcinogenic risk;

LADD – daily average intake during life, mg / (kg · day);

SF – tilt factor mg/(kg·days)⁻¹

$$LADD = \frac{C \cdot CR \cdot ED \cdot EF}{BW \cdot AT \cdot 365}, \quad (1.2)$$

where

C – concentration of the substance in the contaminated environment, mg/m³;

CR – rate of admission to an organism, m³/day;

ED – duration of exposure, years;

EF – frequency of exposure, days/year;

BW – body weight, kg;

AT – period of averaging of the exposure;

365 – number of days in a year.

The risk of development of non-carcinogenic effects in the population from atmospheric air pollution is calculated according to the formula 1.3 (Rukovodstvo po ocnke rizika dlja zdorov'ja naselenija pri vozdeystvii himicheskikh veshhestv, zagrijaznjajushhiih okruzhajushhuju sredu, 2004).

$$HQ = AC / RfC, \quad (1.3)$$

where

HQ – hazard quotient;

AC – average concentration, mg/m³;

RfC – reference concentration, mg/m³.

Research results. Kharkiv and Dnipropetrovsk regions of Ukraine, which are part of the Donetsk-Prydniprovsk economic macro-district - the center of fuel and energy, metallurgical and machine-building industries of state level, have been selected for the research on the assessment of the airborne hazard. The industrial cluster of the region was formed in the "Soviet times" under the conditions of an extensive economy. This kind of economic activity due to neglect of environmental principles and laws has led to significant pollution of local ecosystems and other types of environmental degradation. According to data (Shmandii et al., 2013), Dnipropetrovsk region belongs to the regions with an extremely high level of environmental hazards, and Kharkiv region – to regions with a high level of environmental hazards.

It should be noted that as of 2018, about 2.68

and 3.21 million people live permanently within the limits of Kharkiv and Dnipropetrovsk regions, respectively. The complicated ecological situation in a densely populated territory can lead to significant socio-economic losses due to the increased risk of morbidity and mortality. Thus, the state of the natural environmental components of the region, including the quality of the air, requires special control by the authorized bodies of state power.

Today, the tasks of monitoring the quality of atmospheric air within the settlements of the studied territory are implemented by the Regional Hydrometeorological Centers. Monitoring is carried out daily at specially equipped stations in the largest cities of Kharkiv and Dnipropetrovsk regions: Kharkiv, Dnipro, Kryvyi Rih and Kamianske. The monitoring programme includes indicators of common pollutants and substances that are monitored at regional and local levels.

Sanitary hygienic assessment. Indicators of pollutants' content for the period from 2014 to 2016 were averaged for the preliminary assessment of atmospheric air hazards within the settlements of Kharkiv and Dnipropetrovsk regions. The obtained averaging values were compared with the maximum

and ammonia annual average MPC is characteristic only for Kamianske town– in 2.3 and 1.2 times, respectively. The average annual content of carbon monoxide in it is within the limit-acceptable value – 1 MPC. Unlike the situation in Dnipropetrovsk region, excessive average annual MAC of pollutants in the atmospheric air of the city of Kharkiv has not been recorded.

Assessment of non-carcinogenic risk. A significant excess of the MAC in chemicals and elements indicates a dangerous level of air pollution within the studied cities, which necessitates a detailed assessment of the health risks of the population. Consequently, the risk of development of non-carcinogenic HQ effects is calculated on the condition of inhalation supply of pollutants (Fig. 2).

The results of the study show that the level of total non-carcinogenic risk at simultaneous exposure of pollutants in all cities exceeds the limit acceptable value – 1. In particular, this risk for the population of the city of Dnipro is 19.8 HQ; Kamianske– 23.3 HQ; Kryviy Rih – 19.3 HQ; Kharkiv – 11.9 HQ. It should be noted that the likelihood of development of harmful effects increases in proportion to the increase in the risk value. Thus, the most dangerous level of

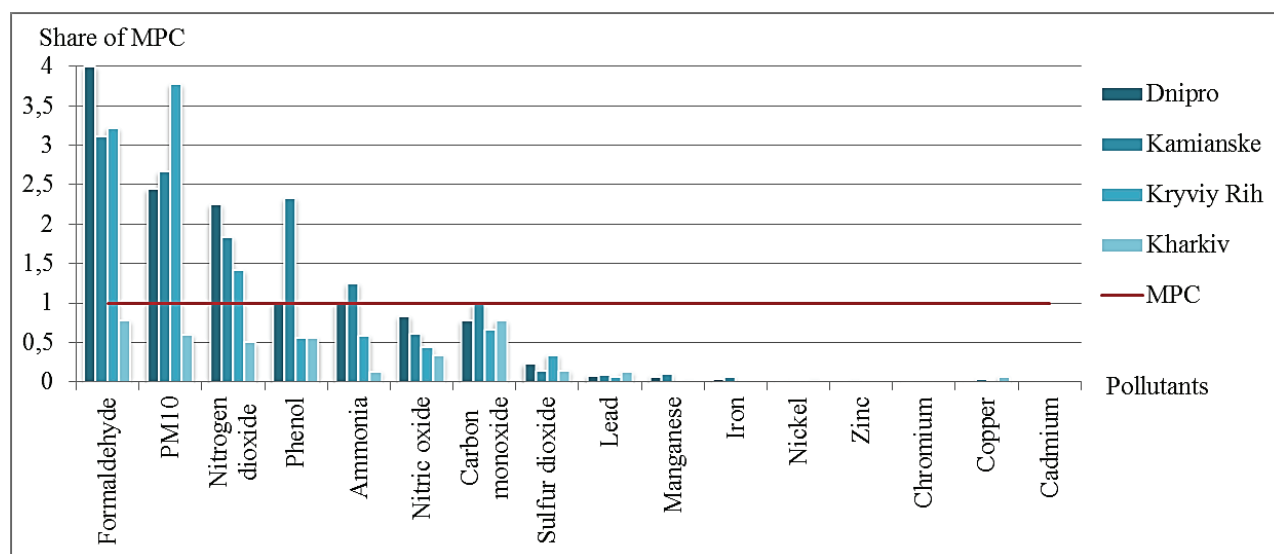


Fig. 1. Assessment of atmospheric air hazard within the settlements of Kharkiv and Dnipropetrovsk regions by criterion of MAC (2014-2016).

permissible concentration – MPC accepted in Ukraine (Fig. 1).

The results of the sanitary-hygienic assessment of atmospheric air show that the average annual concentration of formaldehyde is exceeded – from 3.1 to 4 times; $PM_{2.5}$ – from 2.4 to 3.8 times; nitrogen dioxide – from 1.4 to 2.2 times in all the studied towns of Dnipropetrovsk region. Excess of phenol

atmospheric air pollution among the studied cities is characteristic for the town of Kamianske, the least dangerous – for the city of Kharkiv.

Characterizing the non-carcinogenic risk of certain chemicals and elements, we note that the greatest danger to the health of the population is the pollution of atmospheric air with $PM_{2.5}$ – the permissible level of risk in all cities was exceeded

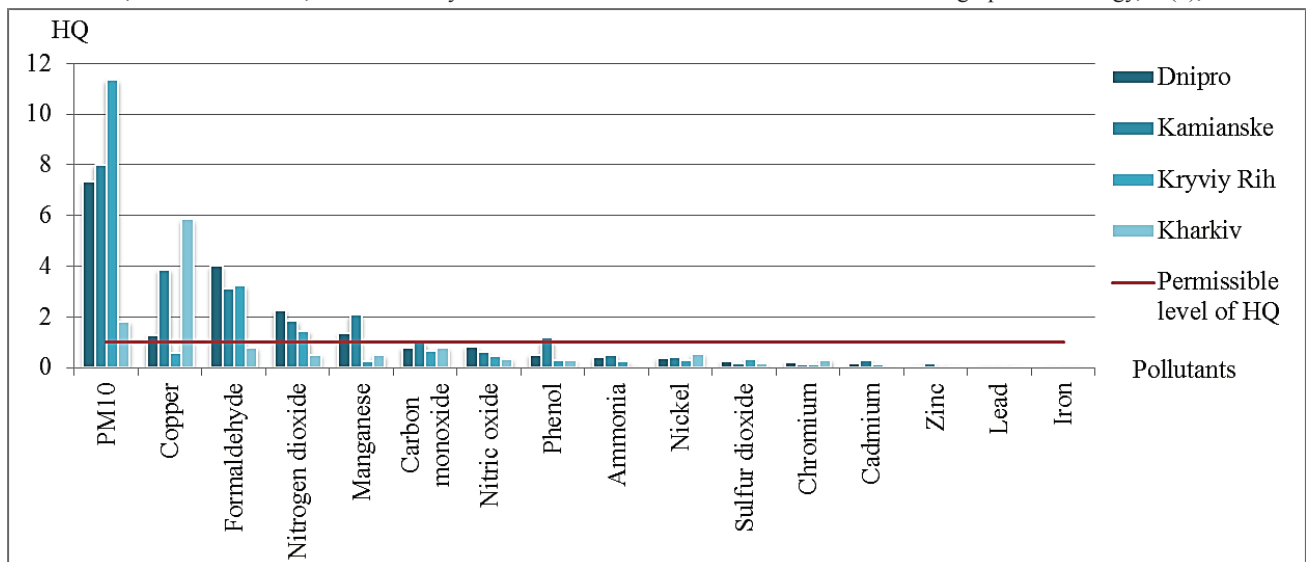


Fig.2. Assessment of non-carcinogenic risk from atmospheric air pollution within the settlements of Kharkiv and Dnipropetrovsk oblasts (2014 - 2016)

from 1.8 to 11.3 times. In the towns of Dnipropetrovsk region the predominant pollutants are formaldehyde and nitrogen dioxide. The range of non-carcinogenic risk values for formaldehyde is from 3.1 to 4 HQ; by nitrogen dioxide – from 1.42 to 2.2 HQ.

Significant local differences can be traced in pollution of atmospheric air with copper and manganese. Thus, the highest value of non-carcinogenic risk for copper is characteristic for the population of Kharkiv city – 5.8 HQ. The non-carcinogenic risk indicator for the population of Kryviy Rih for copper and manganese, in contrast to other towns in Dnipropetrovsk region, corresponds to the permissible level.

Thus, in the atmospheric air of the studied cities there is an observed excess of the reference concentrations of the following pollutants: $PM_{2.5}$, copper, formaldehyde, nitrogen dioxide, manganese and phenol. These pollutants are capable of causing various harmful effects in the human body. In particular, the influence of $PM_{2.5}$ and other solid particles is associated with cardiovascular and cerebrovascular diseases (Anderson, Thundiyil, & Stolbach, 2012). Excess of copper causes liver disorders and neurodegenerative changes in the body (Uriu-Adams & Keen, 2005), endemic anemia, growth retardation, loss of light sensitivity, etc. (Nekos & Kholin, 2015). Formaldehyde has a proven carcinogenic effect, may cause eye irritation and respiratory tract infections (Rovira, Roig, Nadal, Schuhmacher, & Domingo, 2016). Also, formaldehyde affects the nervous system, respiratory tract, liver and kidneys; can lead to anomalies of fetal development due to teratogenic properties (Malyutina, & Taranenko, 2014). Pollution of atmospheric air with nitrogen dioxide is dangerous because of the risk of respiratory infections in the

interaction of pollutants with the immune system (Chen, Kuschner, Gokhale, & Shofer, 2007). The toxic effects of manganese are connected with neurodegenerative disorders, manganese-induced parkinsonism or manganism (Avila, Robson, & Aschner, 2013). Chronic phenol poisoning can cause damage to the central nervous system, kidneys, liver, respiratory and cardiovascular systems (Shipicyna, Vasilenko, Gadaborsheva, & Chichirov, 2017). Given the significant differentiation of the effects of chemicals and elements, it is advisable to identify the critical organs and systems of the human body, subject to the exposure of all studied pollutants (Fig. 3).

The results of the study show that the highest risk of developing non-carcinogenic effects from atmospheric air pollution is characteristic of the following organs and systems: respiratory organs – from 11.1 to 22.3 HQ; cardiovascular system – from 2.9 to 12.3 HQ; immune system - from 1.7 to 4.7 HQ; eyes – from 0.8 to 4 HQ; central nervous system – from 1.4 to 4.6 HQ. The range of values for the risk of normal body development disorder is from 2.7 to 12 HQ. For blood, the greatest risk is related to the formation of methemoglobin – from 0.83 to 3.08 HQ. It should be noted that the formation of methemoglobin leads to the loss of iron ability to bind and transport oxygen in the body (Fatkulin, Gil'manov, & Kostjukov, 2014). When the content of methemoglobin is more than 1% in the blood, a person develops methemoglobinemia – a state that is accompanied by headache, weakness, tachycardia and other negative effects.

Assessment of carcinogenic risk. Among the studied pollutants are chemicals and elements that have a carcinogenic effect, that is, the ability to cause malignant neoplasms. Carcinogens, in particular, include: formaldehyde, nickel, cadmium, lead and

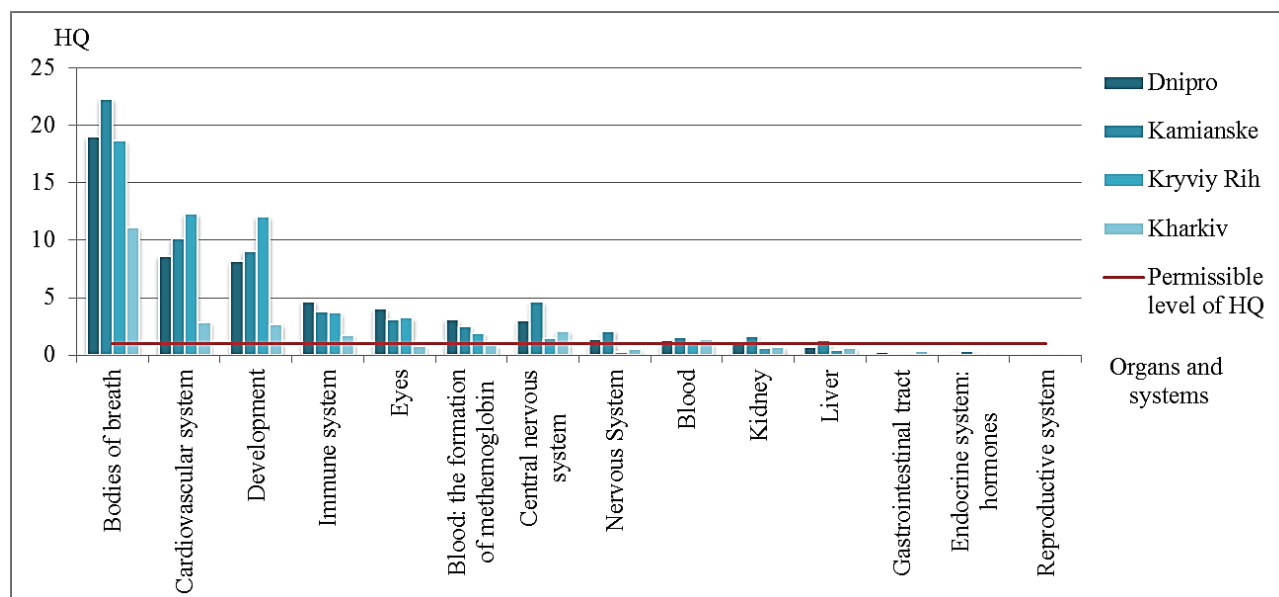


Fig. 3. Risk of development of non-carcinogenic effects from pollution of atmospheric air in organs and systems of the body

chromium. The assessment of carcinogenic risk, CR, was carried out in accordance with the generally accepted methodology (Rukovodstvo po ocenke rizika zdravlja pri vozdeystvii himicheskikh

However, given the limited list of chemicals and elements whose content is subject to atmospheric air monitoring within the studied area, the actual carcinogenic risk is likely to be higher. In particular,

Table 1. Assessment of carcinogenic risk from polluted air (2014 – 2016)

| № | Carcinogen | Dnipro | Kamianske | Kryviy Rih | Kharkiv |
|------------------------|--------------|----------|--------------------------|------------|------------|
| 1 | Formaldehyde | 1,58E-04 | 1,23E-04 | 1,27E-04 | 3,07E-05 |
| 2 | Cadmium | 5,40E-06 | 1,02E-05 | 4,81E-06 | – |
| 3 | Nickel | 4,49E-06 | 4,80E-06 | 3,19E-06 | 6,40E-06 |
| 4 | Lead | 2,84E-07 | 3,20E-07 | 2,40E-07 | 4,40E-07 |
| 5 | Chromium | 2,52E-04 | 1,60E-04 | 1,60E-04 | 3,60E-04 |
| CR total | | 4,20E-04 | 2,98E-04 | 2,95E-04 | 3,98E-04 |
| Assessment of CR level | | | Conditionally acceptable | | Acceptable |

veshhesty, zagryaznjajushhiih okruzhajushhuju sredu, 2004), described above (Table 1).

The obtained carcinogenic risk values from atmospheric air pollution are classified into two categories: conventionally acceptable level of risk and acceptable risk level. The lowest carcinogenic risk corresponding to an acceptable level is characteristic of lead. The greatest contribution to the total carcinogenic risk is made by the pollutants: chromium – from 53.6 to 90.6%; formaldehyde – from 7.7 to 43.1% (Fig. 4). Such a distribution is likely to be due to the preponderance of stationary sources of pollution over motor vehicles, which is one of the main factors of lead pollution of the environment

Thus, the carcinogenic risk from atmospheric air pollution in the cities of Kharkiv and Dnipropetrovsk regions corresponds to the permissible level.

there is no ongoing monitoring of the soot content in Dnipropetrovsk oblast and in most other regions of Ukraine – the equivalent of PM_{2.5} according to the international classification, which is a carcinogenic pollutant.

Conclusions

1. Assessment of atmospheric air pollution hazard within the settlements of Kharkiv and Dnipropetrovsk regions was carried out within the framework of the research on the criterion of environmental risks, namely, the risks of carcinogenic and non-carcinogenic effects on the population.

2. The total non-carcinogenic risk from atmospheric air pollution within the studied cities exceeds the permissible level. The range of non-

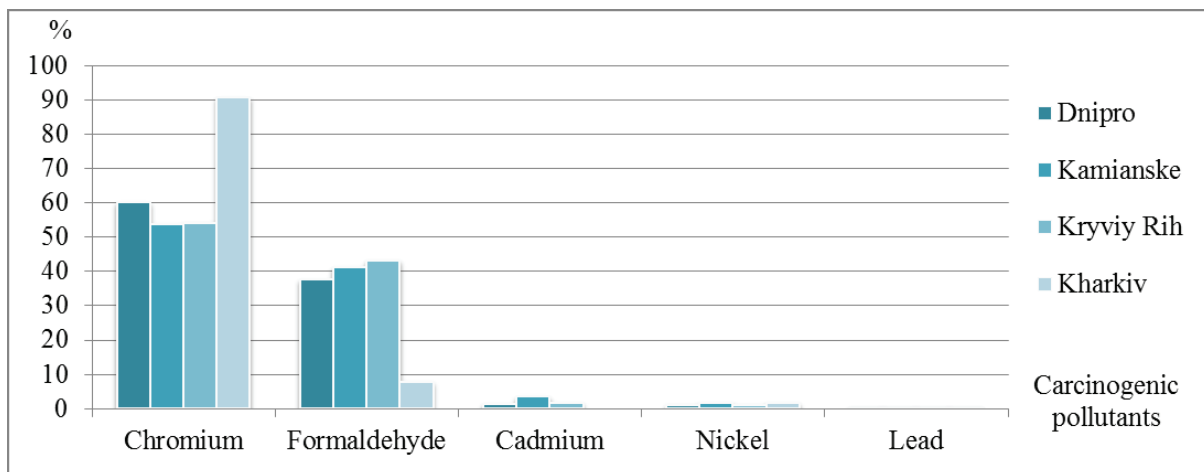


Fig. 4. Distribution of contributors of contamination to total carcinogenic risk

carcinogenic risk varies from 11.9 to 23.3 HQ. The greatest danger is the pollution of air by $PM_{2.5}$, copper, formaldehyde, nitrogen dioxide, manganese and phenol.

3. Pollution of air within the studied cities, above all, is associated with the risk of harmful effects to the respiratory system, blood, eyes, cardiovascular and immune systems, central nervous system, as well as disorders of the human body in general.

4. The total carcinogenic risk from atmospheric pollution in all cities is characterized as conditionally acceptable, chromium and formaldehyde being the most dangerous pollutants.

5. In view of the obtained results, it is expedient to include assessment of the health risks in the system of monitoring and control of the environment in Ukraine; it is advisable to disseminate information and analytical materials among the population on the impact of major pollutants on the human body, in particular heavy metals.

6. Prospects of further research are related to the assessment of risks to the population from atmospheric air pollution, increase in the number of settlements and regions of research, development of approaches to optimization of the air monitoring system.

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