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Assessment of the Risks of Toxic Effects of Atmospheric Air Pollution for Humans (on the Example of Cities in Southern Ukraine)

Alla Kolisnyk[1], Angelina Chugai[1*], Andriy Mozgovyy[2], Iryna Soloshych[3]

[1] Department of Environmental Science and Environmental Protection, Odesa State Environmental University, 15 Lvivska Str., Odesa, 65106, Ukraine

[2] Department of Ecology and Environmental Technologies, Admiral Makarov National University of Shipbuilding, 9 Heroiv Ukrainy Av., Mykolaiv, 54007, Ukraine

[3] Department of Ecology and Biotechnologies, Kremenchuk Mykhailo Ostrohradskyi National University, 20 Pershotravneva Str., Kremenchuk, 39600, Ukraine

* Corresponding author's e-mail: avchugai@ukr.net

ABSTRACT

The significance of the research lies in the fact that atmospheric air is one of the vital components of the natural environment, and a high level of atmospheric pollution can cause toxic effects on human health. Therefore, an important and necessary task is to assess the negative impact of atmospheric air pollution on human health using certain methodological approaches. The aforementioned impact can manifest itself through carcinogenic and immunotoxic, that is, chronic effects. The possibility of solving the task is provided by the „Methodology for assessing the risks of toxic effects on human health from atmospheric air pollution", which is based on the use of a linear-exponential thresholdless model. The research aimed to assess the risks of toxic effects from atmospheric air pollution in the cities of southern Ukraine for the population. The specified methodical approach allows for establishing the level of safety of city dwellers under the conditions of polluted atmospheric air. According to the results of the assessment of the carcinogenic risk of chronic intoxication of the population of four cities in the south of Ukraine in 2015–2020, it was established that the highest level of total risk from atmospheric air pollution was observed in the city of Odesa. The total risk index at maximum exposure for the city of Zaporizhia is lower compared to Odesa. In 2019–2020, a slight increase in the risk of intoxication of the population of the city of Zaporizhia was noted. The level of total risk of chronic intoxication of the population in the city of Kherson according to average indicators is lower than in the city of Zaporizhia. The level of danger for the population in the city of Mykolaiv is the lowest; there was a clear trend of reducing the risk of intoxication during the study period. The safest conditions for the population are in the city of Mykolaiv.

Keywords: ecological risk, atmospheric pollution, chronic intoxication, risk of toxic effects, linear-exponential model.

INTRODUCTION

The problem of assessing the risks of adverse consequences from the influence of negative factors on people lies in the fact that factors of various origins and levels have a simultaneous, complex influence. Environmental risk assessment methods cannot cover all the diversity of problems related to environmental risk assessment and describe only the most important of them. For a long time, assessing the risk to human health caused by environmental pollution was the task of experts in toxicology and hygiene. This was due to the need to take into account a large number of factors that determine the nature of the impact of harmful substances on the human body. The techniques that allow obtaining approximate risk estimates based on such indicators as the hazard class, and the frequency of exceeding the maximum permissible concentrations, etc., have now been developed, but not all of these techniques take into account the peculiarity and nature of the impact of pollutants on the human body. The most developed and methodologically elaborated are the assessments of risks to humans from water and air pollution.

With regard to aquatic environments, along with a significant number of publications on water treatment technologies (Malovanyy et al., 2019; Malovanyy et al., 2020), methods for regulating wastewater discharges from the perspective of managing environmental risk from water pollution have been developed (Proskurnin et al., 2022). A new methodology for assessing the potential risk to public health in recreational water use, which combines the identification of potential risk by chemical and bacteriological indicators, has been proposed (Rybalova et al., 2022).

A linear-exponential model was used in the research when assessing environmental risks taking into account the negative effects of atmospheric air pollution, which allows obtaining an accurate assessment of the risks of toxic effects on human health based on a wide range of indicators, such as the concentration of air polluting substances, their danger classes, the duration of exposure to polluted atmospheric air, and the parameters that take into account the peculiarities of the toxic properties of substances.

On the basis of the results of the analysis of research and publications in the field of work, it was established that the attempts to research the risks of toxic effects from atmospheric air pollution for people are rare. In earlier medical-ecological studies of the importance of risk for the ecological security of Ukraine (Kachynskyi & Serdyuk, 1995) and the study of environmental risk for public health (Pavlov, 2001), the authors note that the risk for public health should be understood as the multiplication of the probability of a negative event and the amount of possible damage from it. This form of risk definition, according to the authors, is quite convenient, as it allows combining heterogeneous data about the object and subject of danger together to obtain integral risk assessments from an unlimited number of negative processes of any origin. To assess the environmental risk from atmospheric air pollution in works (Snesar, Kolisnyk & Chernyakova, 2019; Kolisnyk et al., 2022), the methodology for determining the size of the risk of shortening life expectancy under the influence of atmospheric air pollutants, which is based on a scientifically based „dose-effect" dependence, was used. Such dependence implies the fact of increased risks of shortening the life expectancy of the population in industrialized areas and urban ecosystems. The study (Ting, Kaile & Tao, 2022) attempted to establish the relationship between air pollution and public health using a spatial econometric model. As a result, it was found that there is a significant „U-shaped" spatial correlation between the air emissions indicator and the level of public health. The authors of the research (Fan et al., 2022) studied the short-term impact of air pollution on medical losses and found that with an increase in the level of episodic air pollution and the duration of persistent pollution, the frequency of visits by people to medical institutions and medical losses simultaneously increases. In this research, an attempt was made to apply one of the methods that allow taking into account the negative impact of polluted atmospheric air on the health of the population, which was previously studied only by experts in toxicology and hygiene. It is undeniable that there is a real danger to human health from atmospheric air pollution and various methodological approaches attempt to take into account the dependence between the fact of pollution and the actual consequences for health, but it is equally important to warn people about potential dangers. This issue is discussed in a study (Ling et al., 2022), the authors of which focused on the study of global efforts to overcome the consequences of urban air pollution for public health. In our opinion, the application of any of the methods of environmental risk research should make it possible to formulate specific recommendations for preserving people's health. Such methods can also be considered the economic approach to assessing the risks of anthropogenic impact on human safety, which was used to rank the territory of Ukraine in the paper (Gadetska & Kuzmych, 2015).

MATERIALS AND METHODS

The research aimed to assess the risks of toxic effects for the population from atmospheric air pollution in the cities of southern Ukraine. For this purpose, various methodological approaches are used, which are described, for example, in the manual (Karayeva & Varava, 2018).

The authors of this study applied the „Methodology for assessing the risks of toxic effects on human health from atmospheric air pollution". The risk assessment, which is performed on its basis, assumes the implementation of a scenario in which the population is exposed to a toxicant the concentration of which in the air is c (mg/m^3), the exposure time τ is at least 30 minutes, and the risk of disease is a function of the dose of the toxicant that entered the body of an average representative of a population group over a lifetime. Concerning air pollution, the dose of a toxicant can be estimated based on data on the concentration of the toxicant in the air and the duration of people's exposure to polluted air (Lysychenko, Khmil & Barbashev, 2011).

To express the risk of chronic intoxication – Rp (including the carcinogenic risk) associated with atmospheric air pollution, a linear-exponential thresholdless model is used (Karayeva & Varava, 2018):

$$Rp = 1 - exp\left(-\mathrm{UR} \times \tau \times c^{ß}\right) \quad (1)$$

where: UR – the unit risk – is the proportionality factor that relates the risk value to the concentration of the toxicant;
c – the concentration or dose of a substance that harms the human body during the exposure time τ;
ß – a coefficient that takes into account the peculiarities of the toxic properties of substances.

The parameters of Equation 1 are presented in a form more convenient for performing practical calculations (Karayeva & Varava, 2018):

$$Rp = 1 - exp\left[\left[\begin{matrix} -0.174 \times \\ \times \left(\dfrac{c}{\mathrm{MPC_{da}} \times \mathrm{K_p}}\right)^{ß} \times \tau \end{matrix}\right]\right] \quad (2)$$

where: $\mathrm{MPC_{da}}$ – the maximum permissible average daily concentration of a chemical substance in the atmospheric air of populated areas, mg/m^3.

This concentration should not harm the human body directly or indirectly when inhaled for an indefinite time. The parameters ß and K_p, recommended for calculations, are presented in Table 1. Regardless of the hazard class of the substance at a concentration that does not exceed the $\mathrm{MPC_{da}}$ value, ß = 1,00 (Karayeva & Varava, 2018).

The dependence of the risk of chronic diseases caused by atmospheric air pollution on the multiplicity of exceeding the MPC for substances of different hazard classes is not direct, but linear-exponential. At the same time, the potential risk of disease in the population is a function of the multiplicity of exceeding the concentration of the toxicant in atmospheric air for substances of different hazard classes

RESULTS AND DISCUSSION

The paper presents the results of the assessment of the carcinogenic risk of chronic intoxication of the population from polluted atmospheric air in the cities of Southern Ukraine – Odesa, Mykolaiv, Kherson, and Zaporizhia for the period 2015–2020. The initial data for the assessment were the average annual concentrations of pollutants obtained from the network of stationary observation points. The assessment was carried out to take into account the dangerous impact of the following pollutants: dust, carbon monoxide (CO), nitrogen dioxide (NO_2), nitrogen oxide (NO), phenol (C_6H_5OH), hydrogen fluoride (HF), formaldehyde (HCNO) and sulfur dioxide (SO_2).

On the basis of the MPC method (Safranov & Kolisnyk, 2021), indicators of the multiplicity of exceeding the MPC of individual pollutants were calculated. For the cities of Odesa and Mykolaiv, it was established that the priority pollutant in atmospheric air is formaldehyde; for the city of Kherson – nitrogen dioxide and formaldehyde; for Zaporizhia – nitrogen dioxide and phenol.

The risk of chronic intoxication was calculated according to formula (2) for each of the years of the study. At the same time, the exposure time τ is set as a variable from 1 to 24 hours of the population being in polluted atmospheric air. The complex of pollutants in the atmospheric air of each of the four cities is individual. Figure 1 presents

Table 1. Parameters for calculating the risk of chronic intoxication associated with atmospheric air pollution (Karayeva & Varava, 2018)

Toxicant hazard class	Characteristics of the substance	ß	K_p
1	Extremely dangerous	2.40	7.5
2	Highly dangerous	1.31	6.0
3	Moderately dangerous	1.00	4.5
4	Low risk	0.86	3.0

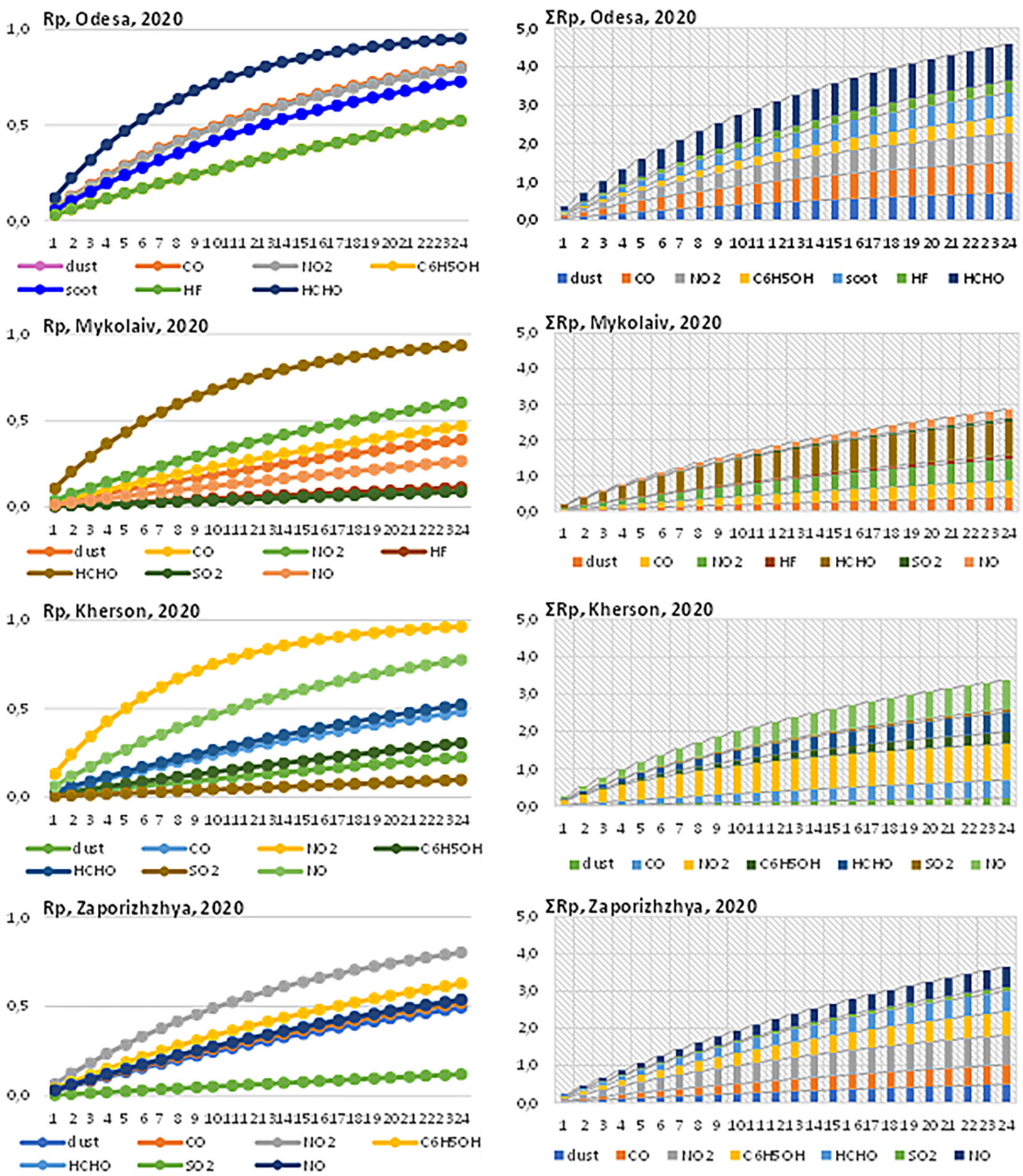

Figure 1. Change in the carcinogenic risks of chronic intoxication by individual pollutants and the total carcinogenic risk depending on the time of exposure (in the year 2020)

the results of calculations (risk from exposure to individual pollutants and total risk by groups of substances) for the cities of southern Ukraine for the year 2020 (an example of one of the six years).

The analysis of the graphs of changes in total risks makes it possible to establish the safe time for the population spent outdoors by calculating the exposure time τ, which corresponds to the risk value of the total negative impact of the pollutant group ΣR_p, which is equal to 1.

For the population of the city of Odesa, the highest carcinogenic risks of chronic influence during the entire period of the study were from the exposure to formaldehyde. In 2020, no more than 3.3 hours a day were a safe time to stay in the open air. At the maximum daily exposure time (24 hours), the value of ΣR_p reaches 4.59 units, which indicates that the limit value is exceeded by more than four times.

The greatest carcinogenic risks for the population of the city of Mykolaiv are also associated with a high content of formaldehyde, the risks from exposure to which are significantly greater compared to the risks from other pollutants. According to the values of ΣR_p in 2020, it was safe to stay outdoors for no more than 5.4 hours a day. The maximum value of the ΣR_p indicator in 2020 was 2.87 units, which indicates an almost threefold carcinogenic risk for the population from the total exposure to a complex of pollutants during a 24-hour outdoor stay.

For residents of the city of Kherson, the highest carcinogenic risks of chronic action are noted from nitrogen compounds – dioxide and nitrogen oxide. The priority for negative carcinogenic effects in 2016–2020 was nitrogen dioxide, and in 2015 it was formaldehyde. In 2020, it was safe to stay in the open atmospheric air of the city for no more than 4.1 hours a day. The maximum total carcinogenic risk during a 24-hour stay in the open air in the city reached 3.37 units, which indicates that the permissible value was exceeded by more than three times.

During 2015–2020, in the city of Zaporizhia, the highest carcinogenic risks of chronic effects on the population were noted from the exposure to nitrogen dioxide, which is a priority, and phenol. In 2020, it was safe to stay in the open air for no more than 4.6 hours a day. At the maximum exposure time in 2020, the value of the ΣR_p indicator was 3.65 units, which indicates a corresponding exceedance of the limit value by more than three times.

Figures 2–5 presents the systematized results of calculations of the total carcinogenic risks of chronic intoxication of the population from the exposure to pollutant complexes over the entire study period for the duration of outdoor exposure from 1 to 24 hours for the cities of southern Ukraine. It is logical that when the exposure time increases, the value of the risk also increases since they are directly related. Therefore, each subsequent of the twenty-four curves is located higher in the graphic plane than the preceding one. When comparing the graphical trace of the curves of total risks of chronic intoxication of the population, it is important to rank them and establish a sequence from the city with the highest risks of intoxication of the population to the city with the lowest risk indicators for the population.

The highest indicators of R_p24, which vary in the range of 4.59–5.12 units, are typical for the city of Odesa (Fig. 2). The maximum value of the total risk indicator was observed in 2015; in 2017 and 2019, a slight decrease in the threat level was noted – the values of the indicators almost reached five units, but did not exceed this limit. Minimum values of R_p24 were observed in 2016 and 2020. In 2020 that the level of risk of intoxication was the lowest for the period under study, although during a 24-hour outdoors stay under the influence of a complex of pollutants, it exceeds the limit value by 4.6 times.

The city of Zaporizhia is next in terms of reduction in the level of the total risk of chronic intoxication of the population from atmospheric air pollution. When analyzing the curves of total risks of chronic intoxication (Fig. 3), it was established that, compared to the city of Odesa, the numerical values of the R_p24 indicator for the city of Zaporizhia do not exceed 4.0, i.e., on average, less by 1. The values of the total risk indicator change at maximum exposure (24 hours) in the range of 3.43–3.74 units. The maximum risk for the population from inhalation of a complex of pollutants was noted in 2015. From 2015 to 2018, the risk gradually decreased, and the value of R_p24 reached its minimum (3.43). In 2019–2020, there was a slight increase in the numerical values of the total risk of intoxication in the city of Zaporizhia.

Compared to Zaporizhia, the city of Kherson had a better situation. The level of the total risk of

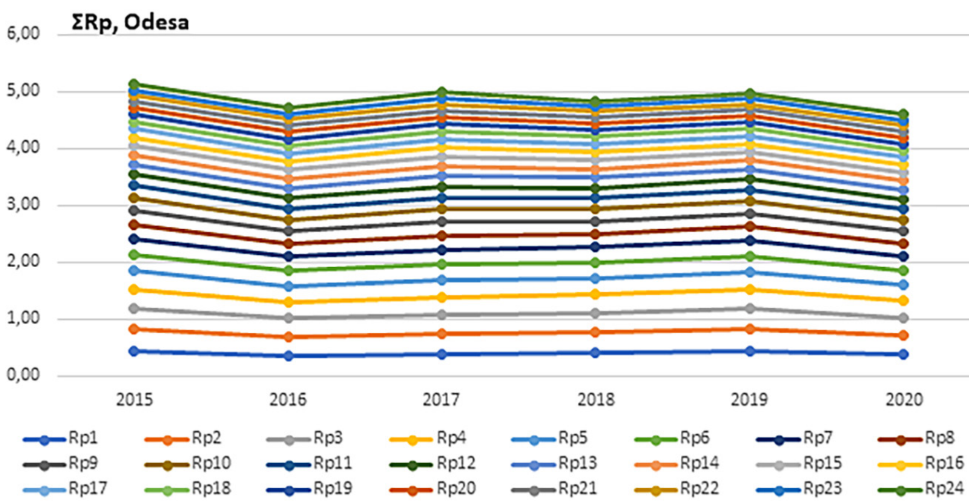

Figure 2. Dynamics of changes in total carcinogenic risks of chronic intoxication associated with atmospheric air pollution in the city of Odesa

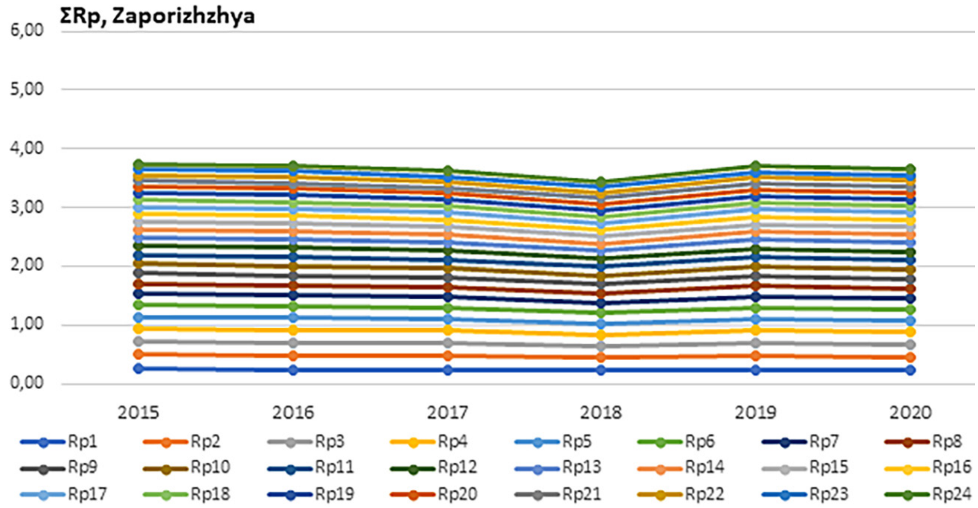

Figure 3. Dynamics of changes in total carcinogenic risks of chronic intoxication associated with atmospheric air pollution in the city of Zaporizhia

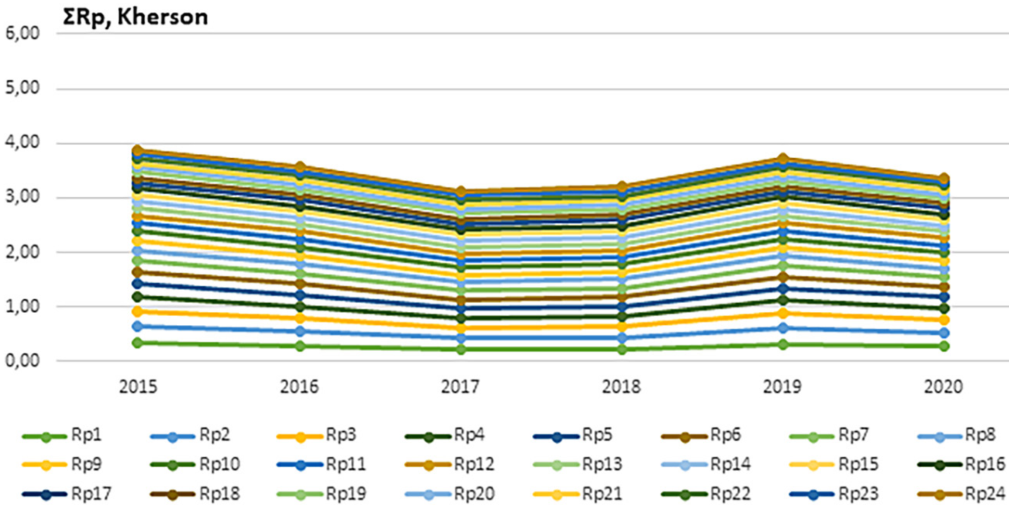

Figure 4. Dynamics of changes in total carcinogenic risks of chronic intoxication associated with atmospheric air pollution in the city of Kherson

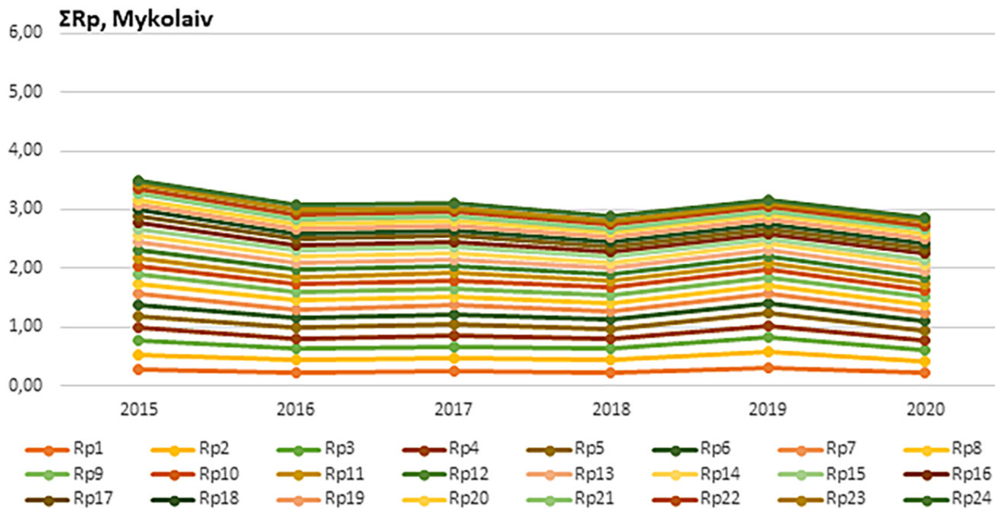

Figure 5. Dynamics of changes in total carcinogenic risks of chronic intoxication associated with atmospheric air pollution in the city of Mykolaiv

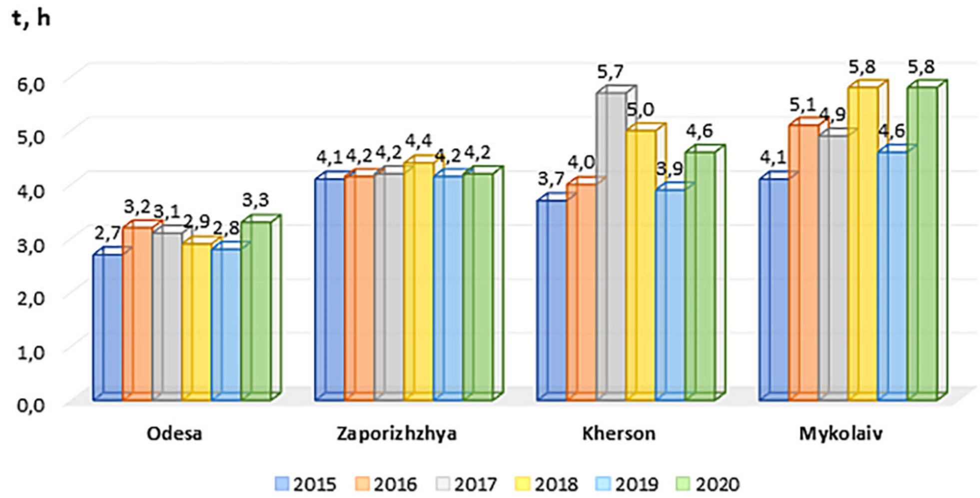

Figure 6. Safe length of stay in the conditions of polluted atmospheric air for people in the cities of southern Ukraine (2015–2020)

chronic intoxication of the population in the city (Fig. 4) according to the average indicators was lower than in the city of Zaporizhia, although it is characterized by a wider range of values (3.12–3.88). The maximum value of R_p24 was noted in 2015. From 2015 to 2017, the indicator decreased and reached a minimum (3.12), and from 2017 the situation has been worsening.

According to the results of the ranking of the cities of southern Ukraine, it was revealed that the city of Mykolaiv is the safest for the population since the total risks of chronic intoxication from inhaling a mixture of pollutants happened to be the lowest when analyzing the situation in four cities (Fig. 5). The R_p24 indicator varied in the range of 2.87–3.5 units. In 2018 and 2020, the lowest risks of chronic intoxication in the population were noted. In fact, a clear trend in reducing the risk of intoxication during the study period was recorded.

Figure 6 presents an estimate of the safe duration of the population's stay in polluted air during the exposure time from 0 to 24 hours. In the figure, the cities are arranged in the order of improvement of safety conditions for the population, which is accompanied by a decrease in the risks of negative effects of atmospheric air pollution on them.

The most dangerous situation regarding the stay of people under the conditions of polluted atmospheric air was in the city of Odesa. For residents of this city, the recommended safe time intervals are very short; their duration did not exceed 2.7 hours in 2015 and 3.3 hours in 2020. This indicates significant risks of chronic intoxication in the population from atmospheric air pollution. In the city of Zaporizhia, a steadily tense situation is noted regarding the risks of chronic intoxication of the population, which directly depends on a fairly high level of atmospheric air pollution by pollutants. The segments of safe outdoor time are insignificant and ranged from 4.1 hours (in 2015) to 4.4 hours (in 2018). The situation in the city of Kherson has been quite heterogeneous over the six years. In 2017, the longest safe exposure time was established at 5.7 hours per day with the lowest recorded level of atmospheric air pollution in the city. Accordingly, the situation with the highest level of pollution (the year 2015) corresponds to a safe time of staying in the polluted air of no more than 3.7 hours per day. Since 2017, the situation had been worsening. The safest conditions for being outdoors without harm to health are observed in the city of Mykolaiv in 2018 and 2020, lasting up to 5.8 hours per day. In 2015, due to the high level of air pollution in the city, there was an increased risk of intoxication, so the safe time of being outdoors that year was only 4.1 hours, which is the worst indicator for the entire period of the study. In general, a steady trend was noted in Mykolaiv in increasing the safe duration of stay of citizens in the open air.

CONCLUSIONS

The paper presents the results of the calculation of the risk of toxic effects for the population from atmospheric air pollution in the cities of southern Ukraine. The assessment was carried out using the „Methodology for assessing the risks of toxic effects on human health from atmospheric air pollution". As a result of the research, some conclusions can be drawn. The used technique is based on the assessment of the risk of adverse consequences for the population from atmospheric air pollution, taking into account the toxic properties of pollutants of various hazard classes. The method makes it possible to establish a safe duration of people's stay in polluted atmospheric air, which is important for minimizing the risk of adverse effects. Formaldehyde is the priority in the complex of air pollutants in the cities of Odesa and Mykolaiv, nitrogen dioxide and formaldehyde in the city of Kherson, nitrogen dioxide and phenol in the city of Zaporizhia. A safe duration of stay for city dwellers under the conditions of polluted atmospheric air has been established. For the population of Odesa, it ranged from 2.7 hours to 3.3 hours. In the city of Zaporizhia, the safe time of being outdoors varied from 4.1 hours to 4.4 hours. In the city of Kherson, the longest safe exposure time has been established up to 5.7 hours per day (the year of 2017) with a minimum of no more than 3.7 hours. In the city of Mykolaiv, the safest conditions for staying outdoors are observed, lasting up to 5.8 hours per day. When analyzing the results of the assessment of the carcinogenic risk of chronic intoxication of the population from atmospheric air pollution in the cities of southern Ukraine, their distribution according to the increasing degree of safety for the population was established: 1 – Odesa, 2 – Zaporizhia, 3 – Kherson, 4 – Mykolaiv. The most dangerous conditions are in the city of Odesa, and the safest – in the city of Mykolaiv.

The results of the conducted research may be of methodological interest for the study of potentially dangerous effects on the population, for the prevention of risks of toxic effects, and for the preservation of the life and health of people in certain regions of Ukraine.

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