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ПРОГНОЗУВАННЯ БЕЗПЕКИ АТМОСФЕРНОГО ПОВІТРЯ У ВЕЛИКИХ МІСТАХ УКРАЇНИ

FORECAST OF ATMOSPHERIC AIR SAFETY IN BIG CITIES OF UKRAINE

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У статті розроблено методику прогнозування безпеки атмосферного повітря у великих містах України. Виконано прогноз щодо безпеки атмосферного повітря у 7 найбільших містах України на період до 2020 р. Інформаційна база дослідження складалась з 14 показників, 5 з яких стосуються кількості викидів шкідливих речовин в атмосферне повітря, а інші 8 відображають концентрації найбільш поширених забруднювачів у повітрі. Окрім цього, використано показник індексу забруднення атмосфери (ІЗА). Оцінка рівня безпеки повітря була проведена у декілька етапів: перший – проведення аналізу вихідної інформації та виконання попередніх розрахунків; другий – розрахунок вагових коефіцієнтів; третій – обчислення коефіцієнту безпеки повітря для кожного міста. Розрахунки показали, що за рівнем безпеки Харків значно випереджає інші міста, охоплені дослідженням. Найвищий ступінь безпеки повітря у місті був у 2008 р., а найнижчий – у 2006 р. Прогнозні дані свідчать, що коефіцієнт безпеки атмосферного повітря м. Харкова протягом наступних років сягатиме близько 0,008 або 〚8*10〛^(-3). Київ, Львів та Одеса мають середній рівень безпеки повітря. В Одесі ситуацію значно погіршує висока концентрація формальдегіду в атмосфері, а в Києві та Львові екологічні проблеми пов'язані з пересувними джерелами забруднення. Низький рівень безпеки повітря мають промислові гіганти Дніпропетровськ, Донецьк і Запоріжжя. Загрозливу ситуацію у цих містах створюють підприємства чорної та кольорової металургії, машинобудування й вугільної промисловості.

The paper deals with the method of predicting the safety of air in major cities of Ukraine. Atmospheric air safety in 7 major cities of Ukraine is forecasted until 2020. The informational basis of the study consists of 14 indicators (indices), 5 of which are related to emissions of pollutants into the air, and the other 8 represent the concentration of the most common pollutants in the air. In addition, the atmosphere pollution index indicator (API) is used. The evaluation of the safety of the air was carried out in several stages: first – the analysis of the original data and preliminary calculations; second – the calculation of weight coefficients; third – the computation of the air safety coefficient for each city. The calculations have showed that by the level of safety, Kharkiv is considerably ahead of the other cities under study. The highest degree of safety of the air was in 2008 and the lowest was in 2006. The predictive data indicate that the factor of safety of the atmospheric air of Kharkiv in the coming years will reach about 0,008 or 〚8*10〛^(-3). Kyiv, Lviv and Odesa have a medium level of air safety. In Odesa, the situation is greatly worsened by the high concentration of formaldehyde in the atmosphere, and in Kiev and Lviv, the environmental problems are associated with mobile sources of pollution. The industrial giants Dnipropetrovsk, Donetsk and Zaporizhzhia have a low level of air safety. The threatening situation in these cities is caused by the steel and nonferrous metals, machinery and coal mining enterprises.

Air is the essential natural resource that needs protection for the life of future generations. For Ukraine, over the past decade, the process of urbanization is firm that increased the anthropogenic impact on the environment, particularly on the atmospheric air. This is due to the work of industrial enterprises, social sphere, transport and other infrastructure objects, most of which are concentrated in major megalopolises.

The development of forecasts of the atmospheric air state is now becoming particularly relevant, since for protection of human health and the environment as a whole it is important to fight against the spread of pollutants in the air and in the places of their formation, and to develop and apply the most effective measures to ensure the safety of the air. It is the ecological forecast of different levels that allows to develop, implement and significantly improve the effectiveness of environmental protection measures in the air, and to avoid, prevent and reduce emissions of harmful pollutants into the air.

The law of Ukraine «On Environmental Protection» includes the items on the necessity of the development and adoption of short-term and long-term forecasting of changes in the environment (Verkhovna Rada of Ukraine, 1991), and in the Law of Ukraine «On Fundamental principles (strategies) of the State Environmental Policy of Ukraine for the period till 2020» there are key target indicators, particularly on the reduction of emissions into the atmosphere (Verkhovna Rada of Ukraine, 2010).

Many Ukrainian and foreign scientists have been engaged in the research of environmental safety and atmospheric air condition. A significant background in this field of research has been prepared by B. Danylyshyn, O. Ral'chuk, A. Stepanenko [3] and other staff members of «The Institute of Environmental Economics and Sustainable Development of NAS of Ukraine», Z. Gerasymchuk [4], M. Zgurovskyi [5], [6], F. W. Stolberg [7], who investigated the environmental and natural-antropogenic safety of cities and regions.

Among recent foreign works it is important to note the research of European scientists in the paper entitled «Green City Index. Europe» [10], the report of the UN – Habitat «State of the World's Cities 2012/2013» [10], as well as reports of the European Environment Agency «Annual report 2012 and Environmental statement 2013» and «Air quality in Europe – 2012 report» [8].

Formulation of research objectives. The aim of the paper is to develop the methodology of forecasting and assessing the safety of the atmospheric air in big cities of Ukraine on the basis of the comprehensive analysis of its current state.

The informational basis of the study consisted of 14 indicators (indices), 5 of which are related to emissions of pollutants into the air, and the other 8 represent the concentration of the most common pollutants in the air. In addition, the atmosphere pollution index indicator (API) is used (Table 1).

For the calculation and forecast of the atmospheric air safety first of all it is necessary to calculate predictive values for 14 indicators for the selected period. The method of trend lines has been used for this. The equation of the trend can be described by a wide range of dependences, in particular:

- ❑ linear – $y = a_0 + at$;
- ❑ power – $y = a_0 t^{u1}$;
- ❑ logarithmic – $y = \log_a x$;
- ❑ index – $y = a_0 a_1^t$;
- ❑ exponential – $y = a_0 l^{a1-t}$ and others.

In our opinion, the most reliable data are obtained from the equation of step functions. Upon obtaining all the necessary predictive values, the assessment of the safety of the atmospheric air in major cities of Ukraine has been calculated.

The assessment of the environmental safety of the atmospheric air is a complex process and involves many aspects that cannot be expressed by only one index. Therefore, the researchers use a system of indices to calculate the final index of the air safety.

Table 1. **Indicators of the atmospheric air state in major cities of Ukraine ***

City	Emissions of pollutants into the atmospheric air, in general, th ton		Stationary sources		Mobile sources		Emissions of pollutants into the atmospheric air per one person, kg		Emissions of pollutants into the atmospheric air per 1 km², ton		Sulfur dioxide concentrations (SO2) in the atmospheric air, mg/m³		Nitrogen dioxide concentrations (NO2) in the atmospheric air, mg/m³		Dust concentrations in the atmospheric air, mg/m³		Formaldehyde concentrations (H2CO) in the atmospheric air, mg/m³		Carbon monoxide concentrations (CO) in the atmospheric air, mg/m³		Benz(a)pyrene concentrations in the atmospheric air, ng/m³		Nitric oxide concentrations (NO) in the atmospheric air, mg/m³		Lead concentrations (Pb) in the atmospheric air, mkg/m³		IPA	
	2004	**2008**	**2004**	**2008**	**2004**	**2008**	**2004**	**2008**	**2004**	**2008**	**2004**	**2008**	**2004**	**2008**	**2004**	**2008**	**2004**	**2008**	**2004**	**2008**	**2004**	**2008**	**2004**	**2008**	**2004**	**2008**	**2004**	**2008**
Dnipropetrovsk	166,2	179,1	111,1	120,3	55,1	58,8	156,6	442,2	410,4	442,2	0,004	0,005	0,070	0,090	0,200	0,200	0,009	0,013	2,000	2,000	2,300	1,700	0,050	0,050	0,030	0,020	12,7	14,7
Donetsk	258,8	164,1	197,5	101,7	61,3	62,4	257,8	458,3	722,9	458,3	0,016	0,022	0,090	0,160	0,300	0,200	0,007	0,013	2,000	2,000	3,400	2,000	0,040	0,050	0,070	0,120	16,7	20,1
Zaporizhzhia	211,7	180,8	151,9	130,4	59,8	50,4	262,7	650,3	761,5	650,3	0,008	0,007	0,060	0,080	0,100	0,100	0,004	0,006	3,000	3,000	2,700	2,200	0,060	0,060	0,010	0,010	12,6	12,2
Kyiv	199,9	275,2	34,8	27,0	165,1	248,2	75,7	329,3	239,2	329,3	0,017	0,008	0,100	0,070	0,100	0,100	0,004	0,006	2,000	1,000	1,000	0,400	0,040	0,040	0,040	0,020	7,5	6,9
Lviv	42,3	47,5	2,9	1,9	39,4	45,6	57,7	277,7	247,4	277,7	0,046	0,044	0,040	0,050	0,200	0,200	0,004	0,008	3,000	3,000	1,000	0,500	0,040	0,040	0,030	0,020	5,6	7,9
Odesa	59,2	76,7	9,9	17,6	49,3	59,1	58,4	323,7	249,9	323,7	0,047	0,037	0,080	0,050	0,200	0,200	0,018	0,018	3,000	3,000	1,000	0,800	0,050	0,030	0,020	0,020	19,1	17,4
Kharkiv	91,6	74,8	6,9	6,0	84,7	68,8	62,6	244,4	299,3	244,4	0,007	0,007	0,030	0,030	0,100	0,100	0,003	0,003	2,000	2,000	1,600	0,700	0,020	0,020	0,050	0,020	5,9	3,7
	2010	**2012**	**2010**	**2012**	**2010**	**2012**	**2010**	**2012**	**2010**	**2012**	**2010**	**2012**	**2010**	**2012**	**2010**	**2012**	**2010**	**2012**	**2010**	**2012**	**2010**	**2012**	**2010**	**2012**	**2010**	**2012**	**2010**	**2012**
Dnipropetrovsk	167,7	168,5	110,0	110,4	57,7	58,1	166,5	168,7	414,1	416,0	0,004	0,006	0,070	0,090	0,300	0,300	0,009	0,011	2,000	3,000	0,900	0,800	0,050	0,050	0,030	0,020	9,7	11,6
Donetsk	136,7	127,6	80,2	71,6	56,5	56,0	141,2	133,6	381,8	356,4	0,028	0,011	0,160	0,130	0,300	0,300	0,010	0,008	2,000	2,000	1,500	1,700	0,070	0,060	0,080	0,040	14,1	13,1
Zaporizhzhia	156,2	139,2	109,6	92,3	46,6	46,9	200,0	180,1	561,9	500,7	0,008	0,009	0,090	0,090	0,100	0,100	0,006	0,005	3,000	2,000	1,600	0,900	0,050	0,070	0,030	0,030	10,4	8,7
Kyiv	265,3	259,2	28,6	32,9	236,7	226,3	95,3	92,1	317,5	297,8	0,013	0,016	0,080	0,110	0,100	0,100	0,008	0,009	1,000	1,000	0,400	0,300	0,010	0,020	0,030	0,030	7,4	9,8
Lviv	44,0	41,9	2,0	1,7	42,0	40,2	59,9	57,4	273,1	245,0	0,030	0,025	0,040	0,050	0,200	0,200	0,004	0,005	2,000	2,000	0,300	0,400	0,030	0,030	0,020	0,020	5,1	5,6
Odesa	71,7	69,0	14,4	13,1	57,3	55,9	71,0	68,5	302,7	291,3	0,035	0,033	0,050	0,060	0,200	0,200	0,015	0,017	3,000	3,000	0,500	0,400	0,030	0,040	0,020	0,020	13,8	15,5
Kharkiv	68,9	70,8	4,9	5,3	64,0	65,5	47,5	49,1	225,2	202,3	0,007	0,007	0,030	0,030	0,100	0,100	0,003	0,002	2,000	2,000	0,600	0,500	0,020	0,020	0,040	0,030	3,7	3,2

** – Made according to the data of the State Statistics Service and the Central Geophysical Observatory.*

Table 2. **Dynamics of air safety coefficient in major cities of Ukraine***

City	2004	2006	2008	2010	2012	2014	2016	2018	2020
Dnipropetrovsk	$2,62*10^{-2}$	$3,63*10^{-2}$	$3,97*10^{-2}$	$3,83*10^{-2}$	$4,17*10^{-2}$	$3,78*10^{-2}$	$3,79*10^{-2}$	$3,80*10^{-2}$	$3,85*10^{-2}$
Donetsk	$4,82*10^{-2}$	$4,22*10^{-2}$	$5,05*10^{-2}$	$5,20*10^{-2}$	$4,57*10^{-2}$	$4,99*10^{-2}$	$4,99*10^{-2}$	$4,89*10^{-2}$	$4,77*10^{-2}$
Zaporizhzhia	$3,77*10^{-2}$	$4,77*10^{-2}$	$4,12*10^{-2}$	$4,27*10^{-2}$	$3,73*10^{-2}$	$3,86*10^{-2}$	$3,89*10^{-2}$	$3,91*10^{-2}$	$3,96*10^{-2}$
Kyiv	$2,22*10^{-2}$	$2,58*10^{-2}$	$2,12*10^{-2}$	$2,23*10^{-2}$	$2,88*10^{-2}$	$2,65*10^{-2}$	$2,64*10^{-2}$	$2,64*10^{-2}$	$2,70*10^{-2}$
Lviv	$2,40*10^{-2}$	$1,94*10^{-2}$	$2,10*10^{-2}$	$1,25*10^{-2}$	$1,43*10^{-2}$	$2,28*10^{-2}$	$2,35*10^{-2}$	$2,36*10^{-2}$	$2,32*10^{-2}$
Odesa	$3,23*10^{-2}$	$2,69*10^{-2}$	$2,92*10^{-2}$	$2,83*10^{-2}$	$3,03*10^{-2}$	$3,16*10^{-2}$	$3,08*10^{-2}$	$2,98*10^{-2}$	$2,84*10^{-2}$
Kharkiv	$8,77*10^{-3}$	$9,87*10^{-3}$	$4,83*10^{-3}$	$7,66*10^{-3}$	$6,97*10^{-3}$	$8,07*10^{-3}$	$8,00*10^{-3}$	$7,93*10^{-3}$	$7,87*10^{-3}$

** – the lower the value is, the higher level of safety is.*

The evaluation of the safety of the air was carried out in several stages: first – the analysis of the original data and preliminary calculations; second – the calculation of weight coefficients; third – the computation of the air safety coefficient for each city.

At the first stage the standardization of indices, i.e. the transition from absolute to relative indices was made based by the following formula:

$$X_{norm} = \frac{X_n - X_{\min}}{X_{\max} - X_{\min}}; \qquad (1)$$

Where X_{norm} – normalized index;

X_n – the absolute index for which the normalized value is determined;

X_{min}, X_{max} – minimum and maximum value for the corresponding content indicators.

At the second stage weight coefficients for each indicator were calculated, as a particular indicator may have a different impact on the object under study. The weight coefficients were calculated using software IBM SPSS using factor analysis.

In determining the weight coefficient the following data were used: matrix of components of factor analysis and their modular values, the table of explained total variance (value % of variance), and the calculated data of factors from matrix of components and the impact of each factor.

The factors of the matrix of components for each indicator were calculated using the formula:

$$F_{(i)} = \frac{x_{(i)} y_{(i)}}{100}; \qquad (2)$$

where, $x_{(i)}$ – module from the matrix of components;

$y_{(i)}$ – % of variance.

In turn, the calculation of the factor impact $(F_{v(i)})$ for each indicator is defined as the sum of all (for each indicator) $F_{(i)}$.

On obtaining the intermediate values, the weight coefficient for each indicator was calculated by the formula:

$$K_i = \frac{F_{v(i)}}{\sum F_{v(n)}}; \qquad (3)$$

where, $K_{(i)}$ – the weight coefficient of the indicator;

$\sum F_{v(n)}$ – the amount of factor impacts for all indicators.

After receiving the weight coefficients normalized values for each indicator were calculated, taking into account the weight factor X_k :

$$X_{k(i)} = X_{norm} \times K_i; \qquad (4)$$

At the third stage the safety coefficient of the air was calculated for each city which is the sum of all the normalized parameters, taking into account the weight coefficient divided by their number:

$$\frac{\sum X_{k(n)}}{n}; \qquad (5)$$

Thus, using the calculated normalized values the table of dynamics of the air safety coefficient and its predictive values till 2020 (Table 2).

The calculations have showed that by the level of safety Kharkiv is considerably ahead of the other cities under study. The highest degree of safety of the air was in 2008 and the lowest was in 2006. The predictive data indicate that the factor of safety of the atmospheric air of Kharkiv in the coming years will reach about 0,008 or 8.

Kyiv, Lviv and Odesa have a medium level of air safety. In Odesa, the situation is greatly worsened by the high concentration of formaldehyde in the atmosphere, and in Kiev and Lviv, the environmental problems are associated with mobile sources of pollution.

The industrial giants Dnipropetrovsk, Donetsk and Zaporizhzhia have a low level of air safety. The threatening situation in these cities is caused by the steel and non-ferrous metals, machinery and coal mining enterprises.

CONCLUSIONS

Guarantee of environmental protection is impossible without allowing for existing trends of development. Forecast of environmental safety of single parts of the environment, including air, is an essential part of the integrated socio-economic development and allows to evaluate the character of the natural environment in different variants of its development, to identify the dominant relationships between environmental and other subsystems.

This study has made it possible to predict the prospects for the development of air safety in major cities of Ukraine on the basis of the current state in this field. The predictive data suggest that the situation in the cities under study will develop differently. In Dnipropetrovsk and Zaporizhzhia the situation will tend to deteriorate. Donetsk, Odesa and Kharkiv will tend to improve. In Kyiv and Lviv the stable tendency failed to be found.

This field of science needs further attention from scientists and development of new research methods using modern science and technology achievements.

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