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Methodical Bases for Taking into Account the Impact of Air Pollution on the Population Lifespan on the Example of the City of Odessa, Ukraine

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ABSTRACT

The scientifically substantiated "dose-effect" relationship suggests that air pollutants increase the risks of reducing the population lifespan, especially in the industrialized areas and urban ecosystems. A characteristic manifestation of such negative impact consequences is an increase in the level of the population incidence rate and, as a consequence, shortening the lifespan. The paper evaluates and analyzes the impact of air pollution on the Odessa population lifespan. The influence of the city priority air pollutants on the lifespan of the population in the areas of the stationary observation points was considered. Based on the results of assessing the risk of being in the polluted air conditions for three age categories for each observation point, the hazard categories of individual pollutants were determined. In general, of all the pollutants in the air basin of Odessa, the content of carbon monoxide and phenol has the greatest impact on shortening the lifespan of the population.

Keywords: environmental risk, air pollution, shortened lifespan.

INTRODUCTION

Recently, the concept of "risk" has been gaining more and more recognition in the scientific research, which focuses on calculating the probability and the degree of influencing the hazardous factors on the human health. In particular, on the basis of a comprehensive analysis of the statistical data for the various forms of a human activity, a classification of the professional activity conditions according to the degree of their danger was proposed. It follows from the axiom of a potential danger that it is impossible to provide a 100% security guarantee in any activity. Accidents, crashes, catastrophes, which are accompanied by deaths, shortening the lifespan, damaging the health, natural or technogenic environment, the disorganizing impact on the society or the life of the individuals demonstrate the consequences of the dangers. In order to unify, any negative consequences are defined as a harm. Each individual type of harm has its own quantitative expression. For example, the number of dead, wounded or sick persons, the area of the infected territory, the area of the burned forest, the cost of the destroyed buildings and so on. The most universal quantitative method of determining the harm is a cost metod, determining the damage in monetary terms. The second, no less important measure of a possible danger is the frequency with which it may occur, or the risk (Kuzmina & Prikup, 2016).

For many scientists the issue of assessing the risk to the public health under the influence of the polluted air is the subject of a scientific research and the development of the methodological foundations for assessing the risks. In Ukraine, the recommendations for assessing the risk to the public health from the air pollution were approved in 2007 (Ministry of Health, 2007). The general assessment principles proposed by the WHO in 2016 (WHO, 2016), the methodological approaches of the European Environment Agency

(EEA, 2021) are the similar documents. Some approaches to assessing, namely the methods, the typical models, the list of necessary source information are also viewed in the work (Bhat et al., 2021). If we consider the examples of assessing in the urban areas, individual cities, the results of assessing in the city of Mumbai, India (Maji et al., 2017) are interesting. The assessment was performed for three pollutants (PM_{10}, SO_2, NO_2). The excess mortality and morbidity have been found to be mainly due to the increased particulate matter. Regarding the regions of Ukraine, a similar work was performed for the city of Kyiv (Popov et al., 2020). It was determined that the risk values differed significantly in different districts of the city, i.e. a quality of the atmospheric air in the city is unstable. In addition to the city of Kyiv, the assessments were also performed for the other cities in Ukraine, in particular for Cherkasy and Kremenchuk (Chernichenko et al., 2017). The work focuses on the impact of air pollution with carcinogenic pollutants on the development of cancer.

In general, a risk assessment includes 4 stages: 1) a hazard identification; 2) an exposure assessment (the amount of chemicals that is available for adsorpting on the metabolic membranes of the body (lungs, a gastrointestinal tract, skin) during a certain exposure duration); 3) a hazard characteristic (a "dose-effect" relationship); 4) a risk characterization (Shmandiy et al., 2019).

The main effect of the harmful substances – poisoning – can occur in the acute, subacute and chronic forms. In modern conditions, a human body can be exposed to a joint (combined), simultaneous or sequential action of the harmful substances (Kuzmina & Prikup, 2016).

MATERIALS AND METHODS

The dose-dependent response of the organism is usually determined experimentally at the level of the sufficiently high, clearly effective doses, and the assessment of the contamination actual level is carried out by extrapolation. At the same time, the knowledge about the nature of such substances at a small doses level is not often a result of scientific proving, but a consequence of adopting this or that scientific and theoretical concept (Kuzmina & Prikup, 2016).

There is a classification of risk levels, which found that a risk value less than 10^{-6} can be used as a threshold that divides the risk value into the safe and dangerous ones (Kuzmina, 2013).

For a relatively long-term action of toxic substances under the stable conditions, a dose-time-effect dependence is expressed by the following equation (Kuzmina & Prikup, 2016):

$$E = E_m - exp[-k^n \cdot \lambda \cdot C^n\ (t_{gen} - t_{bal})] \qquad (1)$$

where: E is a toxic effect at a given concentration and the time of exposure;
E_m – the maximum effect;
n is a stoichiometric coefficient of the biological reaction;
k is a limiting reaction rate constant;
t_{gen} – the total time of xenobiotic exposure;
t_{bal} – the time to balance the concentrations of xenobiotics in the environment and in the body;
λ – a coefficient of distribution on the organism or the environment;
C – a concentration of the toxic substance in the environment.

One of the approaches to determine the size of the risk of shortening the lifespan under the pollutants influence, taking into account a dose-effect dependence is "Methodology for assessing the risk to public health from air pollution" (Kuzmina, 2013). According to the method, a concentration of the harmful substance, which shortens the lifesppan by one unit of a specific concentration is determined. This specific concentration is a ratio of the average lethal concentration of the harmful substance in the air to the estimated 100 year lifespan (Kuzmina & Prikup, 2016):

$$K_{poll} = LC_{50} / 365 \cdot 100 \qquad (2)$$

Determining the lifespan shortening (RLE_{poll}) is performed as a ratio of the actual concentration of the harmful substance (which is analyzed) to the specific one. RLE_{poll} is a function of a degree of toxicity of the harmful substance and its concentration in the air, the receipt of which is due to the natural or anthropogenic sources. If there is a concentration level that exceeds the maximum permissible concentration (MPC) and becomes persistently irreversible, this indicates that RLE_{poll} is becoming a permanent environmental factor and will act to increase natural shortening the lifespan (RLE_{nat}), influencing the statistics of the full lifespan. It is necessary to take into account a degree of probability (Q_{fact}) of a certain age person living in the conditions of the specified actual concentration (Kuzmina & Prikup, 2016):

$$Q_{fact} = (100 - t_1) \cdot t \,/\, 100 \cdot 24 \quad (3)$$

where: t_1 is an age of the person, years;
t – the time spent in the polluted air, hours;
100 – a conditional estimated lifespan, years;
24 – a day duration in hours.

The limit values for the risk of shortening the lifespan under the influence of $R_{RLEpoll}$ contamination are determined based on the results of the toxicological studies. The acceptable risk of 10^{-6} occurs at the concentrations within the *MPC*, and the risk which is equal to 1 (shortening in life by 100 years) occurs at LC_{50}. The general method of determining the impact is to determine the value of RLE_{poll} and $R_{RLEpoll}$ as a result of several years working in the conditions of a constant air pollution of the working area, which is equal to the concentration that is greater than the *MPC*. The value of RLE_{poll} is calculated by the formula (Kuzmina & Prikup, 2016):

$$RLE_{poll} = (Q_{fact} \cdot K_{fact)} \,/\, (K_{poll}) \quad (4)$$

where: Q_{fact} – a probability of being in the pollution conditions;
K_{fact} – an actual concentration of impurities in the air, mg/m^3. The risk of shortening the lifespan is calculated by the formula (Kuzmina & Prikup, 2016):

$$R_{RLEpoll} = RLE_{poll} \,/\, 100 \text{ years} \quad (5)$$

RESULTS AND DISCUSSION

The work evaluates the impact of gaseous pollutants on the lifespan of the population of Odessa in 2017. The materials of the monitoring observations of the air pollution level in the stationary observation points network were used as the baseline data (Fig. 1). The largest number of points is located in the central part of the city. Wherein the main industrial site is located in the north and to the northwest of the city center. And in the southern and southeastern regions, the sources of air pollution are virtually absent. Unorganized emissions are dominated here and motor vehicles are primarily their sources.

The content of the following pollutants in the air was studied: carbon monoxide *CO*; nitrogen dioxide NO_2; hydrogen sulfide H_2S; phenol C_6H_5OH; hydrogen fluoride *HF*; formaldehyde *HCHO*. The information on sampling at the observation points is given in table.1. The table also provides the information on exceeding the *MPC* (highlighted in gray).

The authors have previously assessed the impact of formaldehyde and hydrogen fluoride in the air of Odessa on the human lifespan, taking into account the»dose-effect» dependence in 2013 (Snesar et al., 2019; Chugai et al., 2019). In 2017, the priority gaseous pollutants in the air of Odessa were the following: carbon monoxide (items 17 and 18); dioxide nitrogen (points 16 and 18); phenol (all the points where the observations were made); hydrogen fluoride (points 10, 17 and 18 where the observations were made); formaldehyde (points 10, 16, 17, 18 and 19).

At the next stage, the values of *RLE* under the influence of the priority gaseous pollutants, the concentrations of which in 2017 exceeded the *MPC* were determined. The calculations were performed for each of the 8 observation points for each month of the year in the open air for 8 and

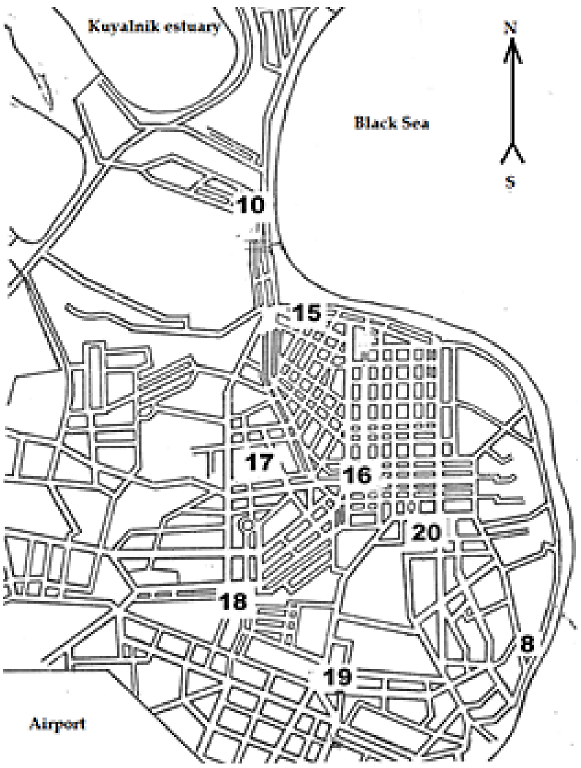


Fig. 1. The stationary observation points in Odessa

Table 1. Atmospheric air sampling at the observation points in Odessa (2017)

Pollutant / observation point	08	10	15	16	17	18	19	20
SO_2	+	+	+	+	+	+	+	+
CO	-	+	+	+	+	+	+	-
NO_2	+	+	+	+	+	+	+	+
H_2S	-	+	-	-	-	+	-	-
C_6H_5OH	+	+	+	+	-	+	+	+
HF	-	+	-	-	+	+	-	-
$HCHO$	+	+	-	+	+	+	+	-

24 hours for the people of different age groups (25, 44, 65 years).

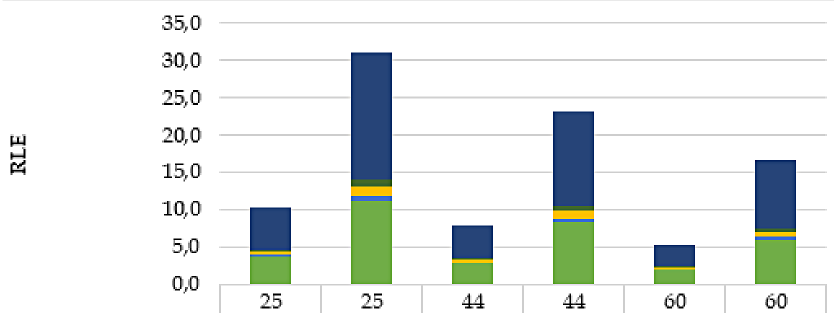
The results of calculating the annual *RLE* for the population were systematized. The most significant is point 18, where the exceeded *MPC* for all pollutants except hydrogen sulfide were recorded (Fig. 2). It is located on Balkivska Street – one of the main highways of the city. According to the methodology, studying the risks of shortening the lifespan for the population living or locating in the point 18 area was performed for all substances except H_2S. The analysis showed the following:

- according to the *CO* content, the minimum value of $R_{RLEpoll}$ for 8 hour staying in the open air for 60 year old people is typical in December, and the maximum for 25 year old people is in April; the minimal loss of life in the contaminated atmospheric air for 24 hours for 60 year old people is typical in December, and the maximum for 25 year old people – in April;
- for NO_2 content, the minimum value of $R_{RLEpoll}$ for 8 hours for 60 year old people is typical in the winter-autumn period, and the maximum for 25 year old people is in August; the minimum loss of the lifespan in the polluted air for 24 hours for 60 year old people was marked in September, and the maximum for 25 year old people was in August;
- the minimum value of $R_{RLEpoll}$ by the content of C_6H_5OH for 8 hours for 60 year old people was marked in February, and the maximum for 25 year old people was in March; the minimum loss of life in the open air for 24 hours for 60 year old people was typical in February, and the maximum for 25 year old people was in March;
- the lowest $R_{RLEpoll}$ by the *HF* content for the 8 hour exposure for 60 year old people was observed in January, May and November, and the highest for 25 year old people was in December; while for 24 hours the minimum $R_{RLEpoll}$ for 60 year old people is in January and the maximum for 25 year old people was in December;
- according to the *HCHO* content, the minimum value of $R_{RLEpoll}$ for the 8 hour exposure for 60 year old people was marked in May, and the maximum for 25 year old people was in October; the shortest duration of the life loss in the polluted air for 24 hours for 60 year old peoplewas typical in May, and the largest for 25 year old people was in October.

Thus, of all the pollutants, carbon monoxide and phenol have the greatest detrimental effect on the human lifespan. The risk assessment of being in the polluted air for the population of Odessa in three age categories was also carried out. The results of calculating the risk of shortening the life ($R_{RLEpoll}$, year^{-1}) for observation point 18 are presented in Figures 3–7.

The analysis of the calculation results showed that:

- a presence in the air polluted with carbon monoxide and phenol (Fig. 5) during 8 and 24 hours is dangerous for people of all ages (Fig. 3);
- being in the air polluted with nitrogen dioxide (Fig. 4) for 8 hours durind a year is safe fot 25, 44 and 60 year old people. For 60 year old people staying there within 24 hours is safe only in September. For all other age groups staying there for 8 and 24 hours is dangerous;
- being in the air contaminated with hydrogen fluoride for 24 hours (Fig. 6) for 25 year old people is safe in January and November. For 44 year old people being there for 24 hours is dangerous only in December. For people of all other ages staying there for 8 and 24 hours is safe during the year;
- being in the air contaminated with formaldehyde for 8 hours (Fig. 7) is safe throughout the year only for 60 year old people. For 44 year old people for 8 hours it is dangerous in January, October, November and December. For 25 year old people for 8 hours it is safe to stay



	25 years. 8 hours	25 years. 24 hours	44 years. 8 hours	44 years. 24 hours	60 years. 8 hours	60 years. 24 hours
carbon monoxide	5,7	17,0	4,3	12,7	2,9	9,1
nitrogen dioxide	0,3	0,9	0,2	0,7	0,2	0,5
formaldehyde	0,5	1,4	0,4	1,1	0,2	0,8
hydrogen fluoride	0,2	0,5	0,1	0,4	0,1	0,3
phenol	3,8	11,3	2,9	8,4	2,0	6,0

Fig. 2. The results of calculating the annual RLE for the population living in the post 18 observation area

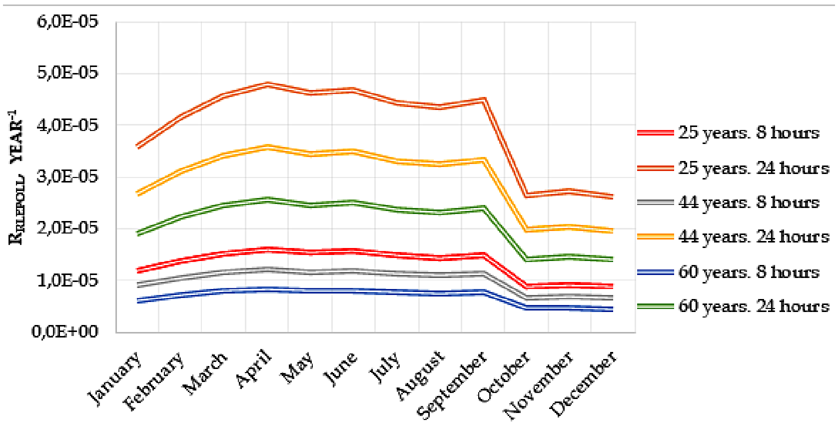


Fig. 3. The results of the RRLEpoll calculation from CO air pollution (observation point 18, Odessa, 2017)

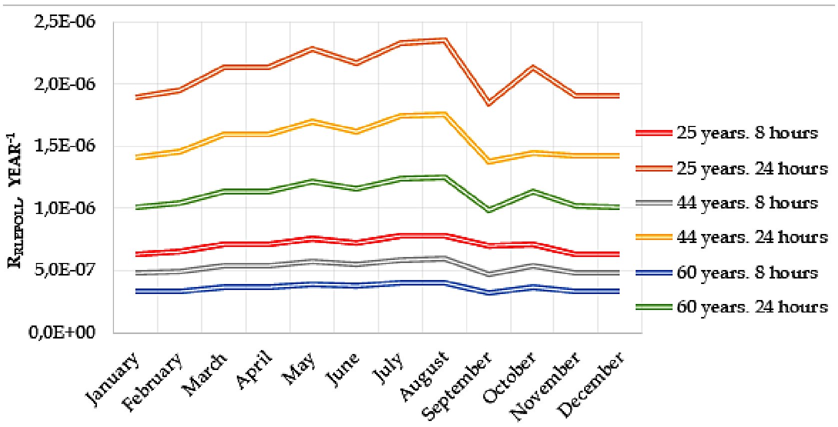


Fig. 4. The results of the RRLEpoll calculation from NO2 air pollution (observation point 18, Odessa, 2017)

there mainly in spring and summer. For 60 year old people for 24 hours it is safe to stay only in May. For 25 and 44 year old people staying there for 24 hours is dangerous.

The risk assessment generalized results of being in the polluted atmospheric air conditions for the population of Odessa of three age categories at all stationary points are presented in Table 2.

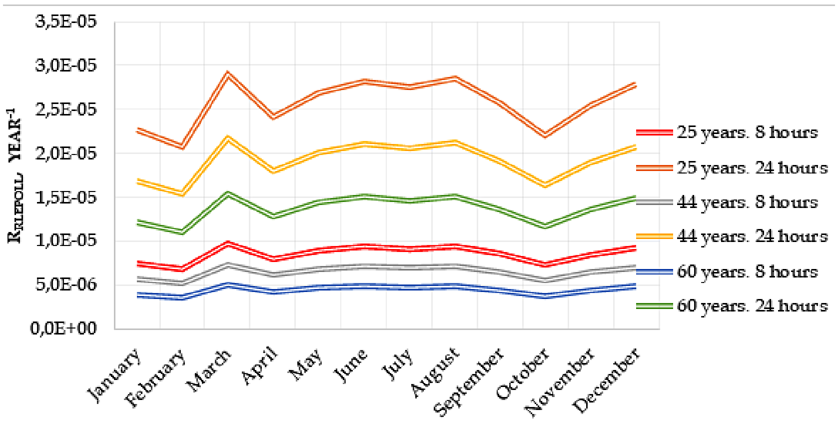


Fig. 5. The results of the RRLEpoll calculation from C6H5OH air pollution (observation point 18, Odessa, 2017)

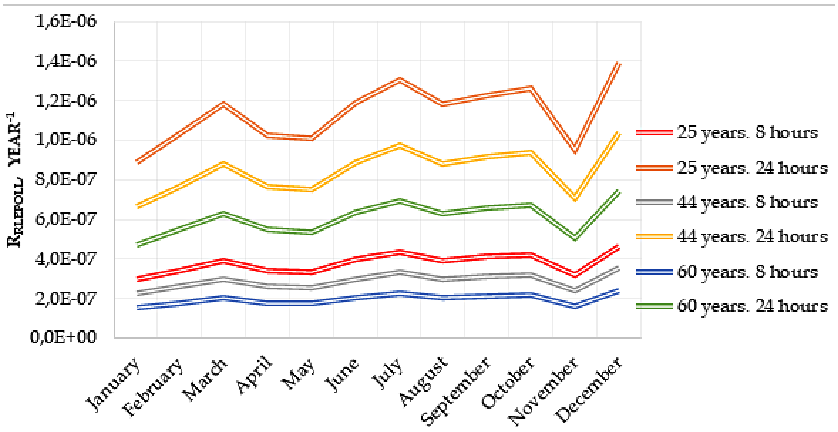


Fig. 6. The results of the RRLEpoll calculation from HF air pollution (observation point 18, Odessa, 2017)

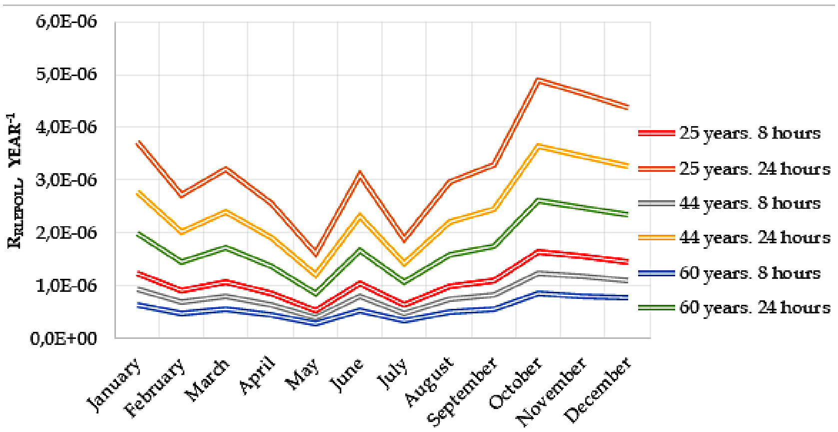


Fig. 7. The results of RRLEpoll calculation from HCHO air pollution (observation point 18, Odessa, 2017)

CONCLUSIONS

In the work according to the atmospheric air monitoring in 2017 in Odessa, an assessment of shortening the lifespan was made, taking into account the increased concentrations of gaseous pollutants. As a result of the study, the following conclusions can be drawn: (1) the most frequent cases of exceeding the *MPC* were observed in the content of phenol and formaldehyde; (2) carbon monoxide (observation point 17 and 18) and phenol (all observation points) have been identified as hazardous substances for the public health; (3) conditionally hazardous substances include nitrogen dioxide (points 16 and 18), hydrogen fluoride (all points where the observations were made) and formaldehyde (most of the points).

Table 2. The results of the risk assessment of shortening the lifespan of the population of Odessa from being in the polluted air conditions (2017)

Pollutant / point	08	10	15	16	17	18	19	20
SO_2	+	+	+	+	+	+	+	+
CO	-	+	+	+	Dangerously	Dangerously	+	-
NO_2	+	+	+	Relatively secure	+	Relatively secure	+	+
H_2S	-	+	-	-	-	+	-	-
C_6H_5OH	Dangerously	Dangerously	Dangerously	Dangerously	-	Dangerously	Dangerously	Dangerously
HF	-	Relatively secure	-	-	Relatively secure	Relatively secure	-	-
$HCHO$	+	Relatively secure	-	Relatively secure	Relatively secure	Relatively secure	Relatively secure	-

In Odessa, a quality of the atmospheric air in different areas differs slightly, due to the impact of the mobile emission sources primarily. In general, the results of calculating the indicators of shortening the Odessa population lifespan under the influence of gaseous pollutants showed that the greatest impact is exerted by the content of carbon monoxide and phenol.

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