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MODELING OF THE INFLUENCE OF HARMFUL EMISSIONS INTO THE ATMOSPHERIC AIR ON THE HEALTH OF THE POPULATION

МОДЕЛЮВАННЯ ВПЛИВУ ШКІДЛИВИХ ВИКИДІВ У АТМОСФЕРНЕ ПОВІТРЯ НА ЗДОРОВ'Я НАСЕЛЕННЯ

This article is dedicated to modeling the impact of hazardous emissions into the atmospheric air on the health and lifespan of the population in Ukraine and worldwide. Polluted air creates an environmental threat to human health and is one of the causes of mortality and morbidity worldwide, which can be prevented. The most dangerous air pollutant for humans is fine particulate matter. These particles are 40 times smaller than the thickness of human hair and invisible to the naked eye. They easily penetrate deep into the lungs, causing inflammation, and then affect the heart, brain, or other organs through the bloodstream. Small doses of PM_{2.5} do not cause an immediate reaction, like a poisonous gas, but they accumulate in the body and can lead to serious problems over time. The most polluted areas in terms of emissions of fine particulate matter are the Donetsk, Dnipropetrovsk, Zaporizhzhia regions, and Kyiv. The development of a state air monitoring system, which has recently begun, should become the basis for a new approach to air quality management.

Keywords: modeling, outliers, fine particles, duration of life, Public health, territory, Air Monitoring.

Бурхливе зростання рівня промисловості, кількості автомобільного транспорту, авіації, промислового виробництва нафтохімічних продуктів, побутових хімічних засобів, обробка сільськогосподарських угідь тощо призвели до прогресуючого збільшення забруднення атмосферного повітря і ця тенденція стрімко продовжується. Щороку в світі від забруднення повітря передчасно помирають мільйони людей. Ще кілька мільярдів щодня змушені дихати насиченим пилом та отруйними сполуками повітрям. Нині загалом близько 90 % дітей проживають у містах, де повітря забруднене різними шкідливими речовинами.

Забруднене повітря створює екологічну загрозу для здоров'я людини і є однією з причин смертності та захворюваності в усьому світі, яким можна запобігти. Наразі 9 із 10 осіб в світі дихають забрудненим повітрям що призводить до передчасної смерті 7 мільйонів людей протягом року.

Метою роботи є дослідження стану атмосферного повітря у різних областях України, а також впливу небезпечних викидів та чинників на здоров'я та тривалість життя населення нашої країни та світу.

Проаналізовано стан атмосферного повітря у різних областях України, а також впливу небезпечних викидів та чинників на здоров'я та тривалість життя населення нашої країни та світу. Найнебезпечнішими факторами, що впливають на зниження середньої очікуваної

тривалості життя в світі є викиди дрібнодисперсних часток та куріння. Значний вплив також мають вживання алкоголю, використання забрудненої води, нещасні випадки та різні хвороби. Поряд зі збільшенням концентрації шкідливих речовин в атмосферному повітрі спостерігалось зростання рівнів захворюваності населення, у тому числі хворобами органів дихання, систем кровообігу, хворобами алергічного походження. В Україні негативного впливу атмосферних забруднень зазнає близько 17 млн. осіб, або 34 % всього населення. Вади розвитку дітей у містах із забрудненням навколишнього середовища трапляються в 3–4 рази частіше, ніж у відносно чистих, хвороби органів дихання реєструються удвічі частіше, загальний рівень захворюваності населення на 25–40 % вищий, вищий також рівень алергічних, онкологічних, серцево-судинних, генетичних та інших захворювань. До найбільш забруднених територій нашої країни відносяться Донецька Дніпропетровська, Запорізька області та м. Київ.

Ключові слова: моделювання, викиди, дрібнодисперсні частки, тривалість життя, здоров'я, територія, моніторинг повітря.

Problem's Formulation

Air pollution is one of the most pressing issues of modern times. A century ago, the composition of the atmosphere was essentially unchanged for the past 300-400 years. However, the rapid growth of industry, transportation, aviation, petrochemical production, household chemicals, aerial agricultural land treatment, landfills, has led to a progressive increase in air pollution, and this trend continues rapidly in the 21st century. Atmospheric air is one of the components of the environment on which human health depends. All living creatures suffer from air pollution, and they are forced to migrate in search of a cleaner environment, which causes an imbalance in ecosystems.

According to the annual report by Bloomberg CityLab, which uses Air Quality Life Index data, air pollution reduces the average life expectancy of humans by 2.2 years, and in the most polluted regions, such as Nepal, India, and Bangladesh, by 5 years. Therefore, research on the emissions of hazardous substances into the atmosphere, as well as their impact on human life expectancy, is an urgent task today.

Analysis of recent research and publications

Such scientists as Kolesnyk V.Ye., Pavlychenko A.V., Kalinina K.R., Stakhiv I.R. have been studying the issues of atmospheric air quality and its impact on public health. The works of Feldman Yu.G., Merezhkina N.V., Ubaydulaev R.U., Penkovich A.A. are dedicated to various aspects of the harmful impurities impact on the development of respiratory diseases. The study's [1, 2] focuses on emissions of dust during the transportation of bulk materials, while the article [3] is devoted to modern means of personal protection for workers in areas with high levels of dust.

Formulation of the study purpose

The objective of this study is to investigate the state of atmospheric air in various regions of Ukraine, as well as the impact of hazardous emissions and factors on the health and life expectancy of the population in our country and around the world.

Presenting main material

There is a saying that the air is never completely clean. If we take the purity of the atmospheric air above the ocean as one unit, then in rural areas the pollution will be 10 times higher, in small cities — 35 times, in large cities — 150 times, and in large industrial centers — a thousand times higher [4].

The World Health Organization (WHO) states that air pollution leads to an increase in illness and mortality worldwide. According to the same organization, air pollution is a priority risk factor for public health, with over 80 % of illnesses being to some extent dependent on air quality. Millions of people die prematurely each year worldwide due to air pollution. Billions more are forced to breathe air saturated with dust and toxic compounds every day. Currently, about 90 % of children worldwide live in cities where the air is polluted by various harmful substances. WHO experts note that particularly serious problems due to air pollution are observed in the vast majority of cities in poor countries. Fig. 1 shows a list of countries in the world by the average life expectancy in 2020 (maximum and minimum values and Ukraine's place in this list).



Fig. 1. List of countries of the world by average life expectancy in 2020

More than 10 billion tons of organic fuels are burned every year in the world, and about 2 billion tons of ore and non-ore materials are processed. Burning coal alone releases about 120 million tons of ash into the atmosphere each year, and up to 300 million tons of other types of dust. According to estimates, over the last 100 years, 1.5 million tons of arsenic, 1 million tons of nickel, 900.000 tons of carbon monoxide, 600.000 tons of zinc, and the same amount of copper have been released into the atmosphere.

Polluted air creates an environmental threat to human health and is one of the causes of mortality and morbidity worldwide that can be prevented. Currently, 9 out of 10 people in the world breathe polluted air, which, according to estimates, leads to 7 million premature deaths per year. Fig. 2 show the impact of hazardous factors on the decrease in the average life expectancy in the world in 2022 based on the data from AQLI publication.

As it can be seen, the most dangerous factors are emissions of fine particles and smoking. The consumption of alcohol, the use of contaminated water, accidents, and illnesses also has a significant impact on people's life expectancy.

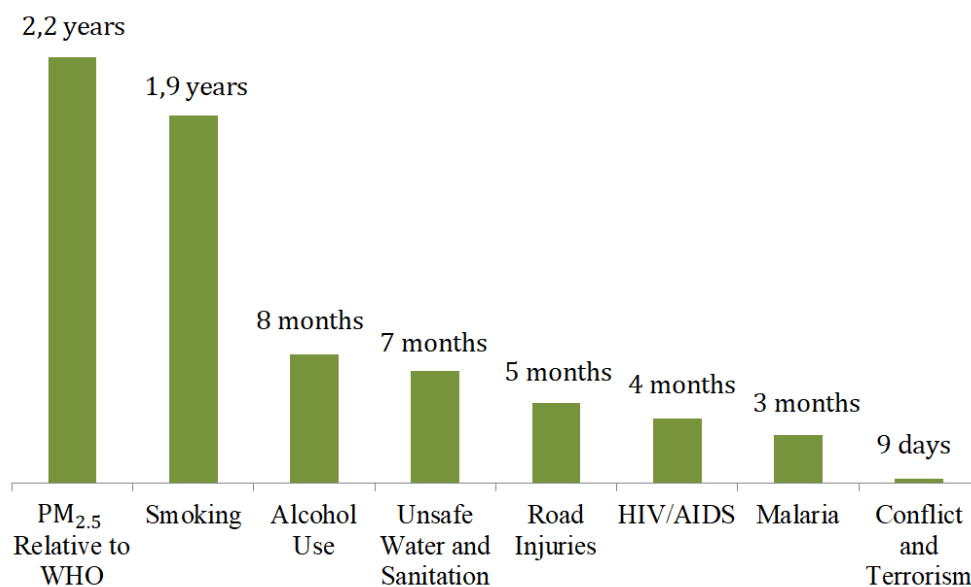


Fig. 2. The impact of factors on the reduction of average life expectancy in the world in 2022

Stakhiv I.R. found that with an increase in the concentration of harmful substances in the atmospheric air, there was an increase in the incidence of the population, including respiratory, circulatory, and allergic diseases. A strong direct correlation was found between the degree of air pollution by dust and the overall level of adult population morbidity for bronchial asthma ($r = 0.88$), circulatory system diseases ($r = 0.91$), ischemic heart disease ($r = 0.89$), and allergic rhinitis ($r = 0.72$) [5, 6].

As you know, the correlation coefficient (Pearson's linear correlation coefficient) shows the closeness of the relationship between random variables, i.e.:

$$r_{xy} = \frac{\sum_{i=1}^N (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^N (x_i - \bar{x})^2 \sum_{i=1}^N (y_i - \bar{y})^2}}. \quad (1)$$

Average values are determined by formulas:

$$\bar{x} = \frac{\sum_{i=1}^N x_i}{N}; \quad (2)$$

$$\bar{y} = \frac{\sum_{i=1}^N y_i}{N}. \quad (3)$$

The formula of the correlation coefficient can also be represented in the following form:

$$r_{xy} = \frac{K_{xy}}{\sigma_x \sigma_y} = \frac{cov(x, y)}{\sqrt{D_x} \sqrt{D_y}}. \quad (4)$$

The correlation moment (covariance) is determined by the formula:

$$K_{xy} = \sum_{i=1}^n \sum_{j=1}^m (x_i - m_x)(y_j - m_y) p_{ij}; \quad (5)$$

$$K_{xy} = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} (x - M_x)(y - M_y) f(x, y) dx dy. \quad (6)$$

The value of the correlation coefficient is interpreted as follows:

$0 < |r_{xy}| < 0,2$ — there is no connection;

$0,2 < |r_{xy}| < 0,4$ — the connection is weak;

$0,4 < |r_{xy}| < 0,7$ — the connection is average;

$0,7 < |r_{xy}| < 1$ — the connection is strong;

$r_{xy} > 0$ — the connection is direct or positive;

$r_{xy} < 0$ — the relationship is inverse or negative.

To check whether the correlation between two variables is statistically significant, the Student's test is also calculated:

$$t = \frac{r_{xy} \sqrt{n-2}}{\sqrt{1-r_{xy}^2}}. \quad (7)$$

In Ukraine, about 17 million people or 34 % of the total population suffer from the negative impact of atmospheric pollution. Developmental disorders in children in cities with environmental pollution occur three to four times more often than in relatively clean ones, respiratory diseases are registered twice as often, and the overall level of population morbidity is 25—40 % higher. The incidence of allergic, oncological, cardiovascular, genetic, and other diseases is also higher. The dynamics of the average life expectancy in Ukraine are presented in Fig. 3.

The most dangerous air pollutant for humans is fine particulate matter. These particles are 40 times smaller than the thickness of a human hair and are invisible to the naked eye. They easily penetrate deep into the lungs, causing inflammation, and then affect the heart, brain, or other organs through the bloodstream. Immediate effects of air pollution on health include irritation of the eyes, nose, and throat, shortness of breath, coughing, and exacerbation of existing health problems.

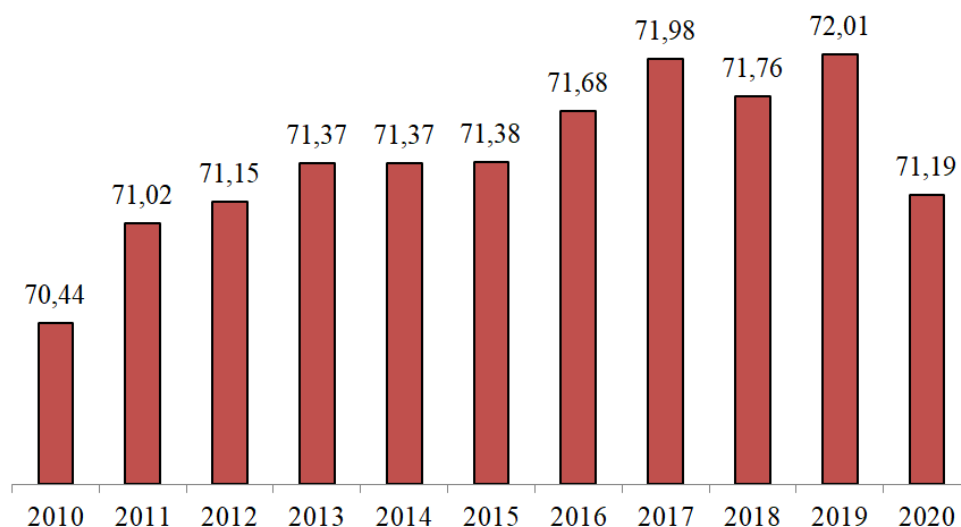


Fig. 3. The dynamics of the average life expectancy in Ukraine over the years

Long-term exposure to polluted air can increase the risk of:

- ischemic heart disease and stroke;
- chronic obstructive pulmonary disease, asthma exacerbations;
- lung cancer, upper gastrointestinal and respiratory tract cancers;
- adverse pregnancy outcomes (i.e., low birth weight, preterm birth, and reduced fetal growth);
- neurodevelopmental deficits in children and certain behavioral disorders (attention deficit hyperactivity disorder);
- diabetes, cataracts.

Air pollution can pose an even greater threat to people during the global pandemic. Researchers from the Harvard T.H. Chan School of Public Health found that higher levels of fine particulate matter in the air are associated with higher COVID-19 mortality rates.

Other studies examining COVID-19 mortality rates in 66 administrative regions in Italy, Spain, France, and Germany found that 78 % of fatal cases occurred in 5 regions with the highest concentration of nitrogen oxide (air pollutant).

Various eco-monitoring services around the world evaluate the actual concentration of particles in the air. The largest online air monitoring program is The World Air Quality Index, which displays the air quality index in cities around the world. This index is calculated based on all air pollutants. Solid particles are classified by size. In countries where governments are concerned about the health of their citizens, such as the EU and the US, measurements of PM concentrations are taken, where particles have a diameter of less than 10 μm (PM10) and less than 2.5 μm (PM2.5). Legal limits on the amount of these particles in the air have also been established. According to the World Health Organization (WHO) standards, the annual average level of PM2.5 should not exceed 10 $\mu\text{g}/\text{m}^3$, and the daily average level should not exceed 25 $\mu\text{g}/\text{m}^3$. Depending on the concentration ($\mu\text{g}/\text{m}^3$) of PM in the air, the air quality index is determined (Tabl. 1) [7].

The most dangerous particles are considered to be PM2.5 particles, which are air pollutants consisting of both solid micro-particles and tiny liquid droplets. Both types range in size from approximately 10 nanometers to 2.5 micrometers. Other designations and names for PM2.5 particles include fine suspended particles (FSP), fine particles, fine particulate matter, fine dispersed particles, and fine dust.

PM2.5 particles are also referred to as the respirable or inhalable fraction. They are so small that they can pass through biological barriers in our bodies, such as the nasal cavity, upper respiratory tract, and bronchi. PM2.5 particles, together with air, enter directly into the alveoli — the tiny air sacs in the lungs where gas exchange occurs between the lungs and blood vessels.

Table 1. Air quality index Depending on the concentration of PM

Air quality index	PM _{2.5}	PM ₁₀
Good	0	0
Satisfactory	12	54
Harmful to the risk group	35	154
Harmful	55	254
Very harmful	150	354
Dangerous	250	424

The greatest danger of PM_{2.5} particles is that, unlike larger particles, they easily penetrate biological barriers and therefore pose the greatest threat to the body. There is no immediate reaction to small doses of PM_{2.5} particles, as with toxic gas, but they accumulate in the body over time and can lead to serious problems.

According to the World Health Organization's report on air pollution and its impact on human health, PM_{2.5} particles reduce life expectancy by an average of 8.6 months. In total, PM_{2.5} particles are associated with 3 % of deaths from cardiovascular and respiratory diseases and 5 % of deaths from lung cancer.

All these particles and droplets smaller than 2.5 micrometers are suspended in the air. They exist in forests and oceans, but pose the greatest danger in cities. Firstly, there are usually more of them in cities, and secondly, the chemical composition of fine aerosols in cities is more dangerous than in nature. The composition of PM_{2.5} aerosols and the parameters of individual particles can vary greatly in different cities.

The main anthropogenic source of these particles is transportation. Internal combustion engines and industrial processes involving the burning of solid fuels (coal, lignite, oil), construction, mining, many types of production (especially cement, ceramics, brick, smelting), and even agriculture — which is a source of ammonia that can form secondary PM_{2.5} particles — can all be sources of these particles in cities. Erosion of road surfaces and the wearing of brake pads and tires can also be sources of PM_{2.5} particles.

Studies have shown that an increase of 10 µg/m³ of PM 2.5 per cubic meter of air reduces life expectancy by 0.98 years. The World Health Organization standard limits the concentration of PM 2.5 to ten micrograms per cubic meter of air. However, nearly three-quarters of Europe's territory does not meet this standard. The worst cases are in Eastern Europe, including Ukraine, Belarus, Slovakia, the Czech Republic, Slovenia, Hungary, Lithuania, and others. The most polluted European country is Poland, especially the cities of Warsaw and Lodz.

Experts also note extremely high levels of PM 2.5 pollution in the Po Valley (Milan, Turin, Bologna) and the region of the Turkish industrial city of Bursa.

From 2013 to 2017, researchers studied the background air pollution and its impact on life expectancy in China. During this period, the government implemented a program to improve air quality with a total budget of \$270 billion. They banned new coal-fired power plants, installed thousands of air monitoring stations, and began limiting car travel. As a result of these measures, PM 2.5 concentrations decreased by 29 % [8].

Regarding Ukraine, the average concentration of PM 2.5 is 9.02 µg/m³. Fig. 4 shows the averaged concentrations of PM 2.5 in the atmosphere by region of Ukraine in 2020.

As can be seen, the most polluted areas of our country include Donetsk region — 11.85 µg/m³; Dnipropetrovsk region — 10.88 µg/m³; city of Kyiv — 10.76 µg/m³; and Zaporizhzhia region — 10.15 µg/m³. It should be noted that the acceptable value of fine particulate matter concentration is 10 µg/m³ according to WHO data.

It should be noted that Ukraine is among the 193 countries that have adopted the Agenda 2030 for Sustainable Development and 17 Sustainable Development Goals as a framework for overcoming all forms of poverty, building a decent life for all, leaving no one behind. SDG 11 includes the indicator of air pollution (11.5), which can be measured using satellite data. This can become an additional source of evidence for assessment or help increase the reliability of local measurements [8].

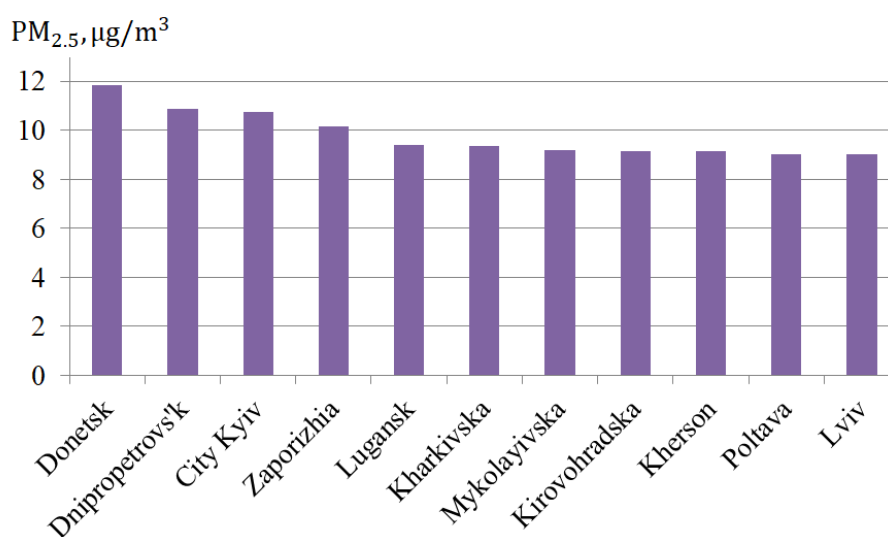


Fig. 4. Average concentrations of fine particulate matter PM_{2.5} in the atmospheric air by regions of Ukraine in 2020

The European Union has adopted legislation to stimulate air quality improvement and create effective mechanisms for quality monitoring and air pollution control. The central element of this legislation is the Directive on Ambient Air Quality and Cleaner Air for Europe, which Ukraine has committed to incorporating into its national legislation under the Association Agreement between Ukraine and the EU.

The implementation of European legislation on air quality includes the establishment of air quality standards, the introduction of air quality monitoring and data collection systems, the creation of a network of automated quality control stations, and many other mechanisms aimed at improving air quality and reducing the negative impact of polluted air on human health and life.

Currently, the development of a national air monitoring system is just beginning in Ukraine, and this should become the basis for a new approach to air quality management.

Conclusions

The state of atmospheric air in different regions of Ukraine and the impact of hazardous emissions and factors on the health and life expectancy of the population of our country and the world have been analyzed. The most polluted territories of our country include the Donetsk, Dnipropetrovsk, Zaporizhzhia regions, and the city of Kyiv. The most dangerous pollutants in the air for humans are fine particulate matter and smoking. Significant impacts on the life expectancy of people also include alcohol consumption, the use of contaminated water, accidents, and illnesses.

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