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Impact of air pollution by particulate matter (PM_{10}, $PM_{2.5}$) on the development of somatic pathologies in children (literature review)

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Abstract: *according to the World Health Organization (WHO), 4.2 million deaths annually are associated with air pollution. Air pollution is the second leading risk factor for mortality among children under the age of five, responsible for an additional 700,000 deaths (15 % of all mortality) worldwide. Therefore, the aim of this study is to analyze literature data, international and domestic regulatory and methodological documents, and information sources to determine the main aspects of the particulate matter impact (in particular PM10 and PM2.5) on the development of children's somatic pathologies. The greatest concern of scientists and health experts is caused by emissions of particulate matter (PM_{10}, $PM_{2.5}$), which causes 10 % of social health losses in Ukraine, resulting in 43,000 premature deaths. Children are particularly adversely affected due to their greater physical activity, immature immune system, underdeveloped respiratory system, and metabolism, which leads to increased lung ventilation and absorption of large volumes of polluted air. The analysis revealed that exposure to PM_{10}, $PM_{2.5}$ can lead to children's psychological complications, autism, and retinopathy; affecting the course of pregnancy and childbirth (spontaneous miscarriages and stillbirths), causing children to develop health problems in the future. It can also increase the prevalence of bronchial asthma, respiratory infections, including acute lower respiratory tract infections, pneumonia, upper respiratory tract infections, and otitis media; and in the future, cardiovascular diseases. At the same time, existing research suggests that allergies, including allergic rhinitis, eczema, and conjunctivitis, are exacerbated and increase in children. Thus, based on the analyzed epidemiological and clinical studies, it is possible to assert a direct and reliable link between exposure to PM_{10} and $PM_{2.5}$ air pollution and an increase in the number of pulmonary diseases among children (in particular, bronchial asthma and pneumonia). Particular attention is drawn to studies on the increased risk of morbidity and progression of type 2 diabetes among children, including the search for causes and mechanisms of its occurrence. The above calls for in-depth epidemiological research, which is limited in Ukraine.*

Keywords: Air Pollution; Particulate Matter (PM_{10}, $PM_{2.5}$); Ventilation; Pulmonary Diseases; Morbidity; impact of air pollution on children's health, somatic pathologies, mortality.

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Introduction

Air pollution is currently one of the most significant medical and environmental issues, resulting in social losses, including diseases and deaths, among both adults and children.

According to the World Health Organization (WHO), its impact on human health is associated with 4.2 million premature deaths per year, with 4 % of cases being lung cancer, 14 % acute lower respiratory infections (including pneumonia), 14 % chronic obstructive pulmonary disease, 68 % stroke, and ischaemic heart disease [1], [2]. At the same time, air pollution is the second leading risk factor for death among children under the age of five [3].

An analysis of statistical data shows that in general, morbidity and mortality from non-communicable diseases (NCDs; in particular, circulatory and respiratory systems) and their prevalence among the population of Ukraine have increased in recent decades and are almost twice as high for women and 2.3 times higher for men than in Europe [4]. According to the «Global Burden of Disease» study, about 10 % of the social costs of the health of Ukrainians are associated with air pollution, which causes about 43,000 premature deaths and almost one million disability-adjusted life years (DALY) [5]. According to the State Hydrometeorological Service of Ukraine (SHS), high levels of air pollution in the country are caused by high exposures to nitrogen dioxide, formaldehyde, phenol and partially total suspended matter, carbon monoxide, hydrogen fluoride [6]. At the same time, in 2021, the average annual exposure to atmospheric particulate matter with a diameter <2.5 μm ($PM_{2.5}$) was 18.5 μg/m^3 (exceeding the WHO recommended standards by 3.7 times), ranking the 56th highest in the world, despite a downward trend in 2023 to 8.6 μg/m^3 (by 1.7 times) due to a significant decline in industrial production as a result of the war [7], [8].

Unfortunately, the assessments conducted are generalised and do not provide an understanding of the impact of air pollution on children's health (including the development of somatic pathologies), which makes this study relevant.

Aim

The aim of this study is to analyze literature, international and domestic regulatory and methodological documents, and other sources of scientific information to determine the key aspects of how particulate matter (specifically PM_{10} and $PM_{2.5}$) impacts the development of somatic pathologies in children.

Materials and Methods

A review of regulatory and methodological recommendations, reports and scientific publications indexed in international scientometric databases was conducted using empirical and bibliographic methods of analysis. The data and information on levels of air pollution and somatic pathologies in children in the world, Europe, and Ukraine were taken from the official (state) websites of the Ministry of Health, SHS, WHO, international and scientific publications, reports, and databases of HEI (Health Effects Institute), IHME (Institute for Health Metrics and Evaluation), UNICEF, and EEA (European Environment Agency).

Review and discussion

In today's realities, the greatest concern among scientists and health experts is the emission of particulate matter (PM_{10}, $PM_{2.5}$), which is the sixth largest risk factor for negative impact on public health [9], [10]. It has been established that about 30 million Europeans live in areas where PM_{10} and $PM_{2.5}$ concentrations are at least four times higher than the WHO recommendations [11]. Ukraine is one of the countries most affected by air pollution in Europe [12], [13].

The main sources of total anthropogenic emissions of primary particulate matter (PM_{10} and $PM_{2.5}$) into the air are fuel combustion at various facilities (40-55 %); industrial processes (15-30 %) and motor vehicles (10-25 %) [14]. Their emissions can also be established by natural sources, namely as a result of dust storms, wildfires, weathering, decomposition of living organisms, etc. As for the processes of PM_{10} and $PM_{2.5}$ intake and formation, they can be directly emitted into the atmosphere or formed in the atmosphere from gaseous precursors (in particular, non-methane volatile organic compounds, nitrogen oxides, sulfur dioxide, etc.). The most important characteristics of PM are their

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linear size and content (exposure) in ambient air [16]. According to EN 481, PM is divided into three fractions: «Inhalable» fraction – particles (< 100 μm) that enter the body through the nose and mouth, where they are deposited; «Thoracic» fraction – particles (< 10 μm) that pass beyond the larynx but do not penetrate the bronchi; «Respirable» fraction – particles (< 4 μm) that easily penetrate the lungs and settle in the alveoli due to Brownian motion [17]. The greatest impact on human health belongs to the «Respirable» fraction, which, bypassing the alveolar-capillary barrier, dissolves in mucus and, being absorbed through the mucosal epithelium, can enter the blood, intercellular fluid, and lymph. At the same time, insoluble particles that enter the alveoli settle on the walls of the airways. If they have not been neutralized by macrophages, they penetrate the biological membrane and are carried by the blood and lymph flow to various organs and tissues, forming dust accumulations in the liver, kidneys, and other organs [16].

Air pollution has a more adverse effect on children due to their immature immune system, underdeveloped respiratory system, and metabolism. As a result, their defense mechanisms against hazardous pollutants do not work as well as those of adults. Children spend most of their leisure time outdoors, are physically active, and tend to breathe through their mouths, which leads to an increase in the intensity of lung ventilation, thereby absorbing a large volume of air and increasing the concentration of air pollutants in it (Fig. 1) [18], [19], [20].

According to HEI, IHME, and UNICEF («State of Global Air /2024»), 700,000 deaths of children under 5 years old are associated with air pollution, which is 15 % of all deaths and indicates almost 2,000 children dying due to severe health effects caused by air pollution [3].

Numerous epidemiological studies have shown that long-term exposure to air pollution leads to children's psychological complications,

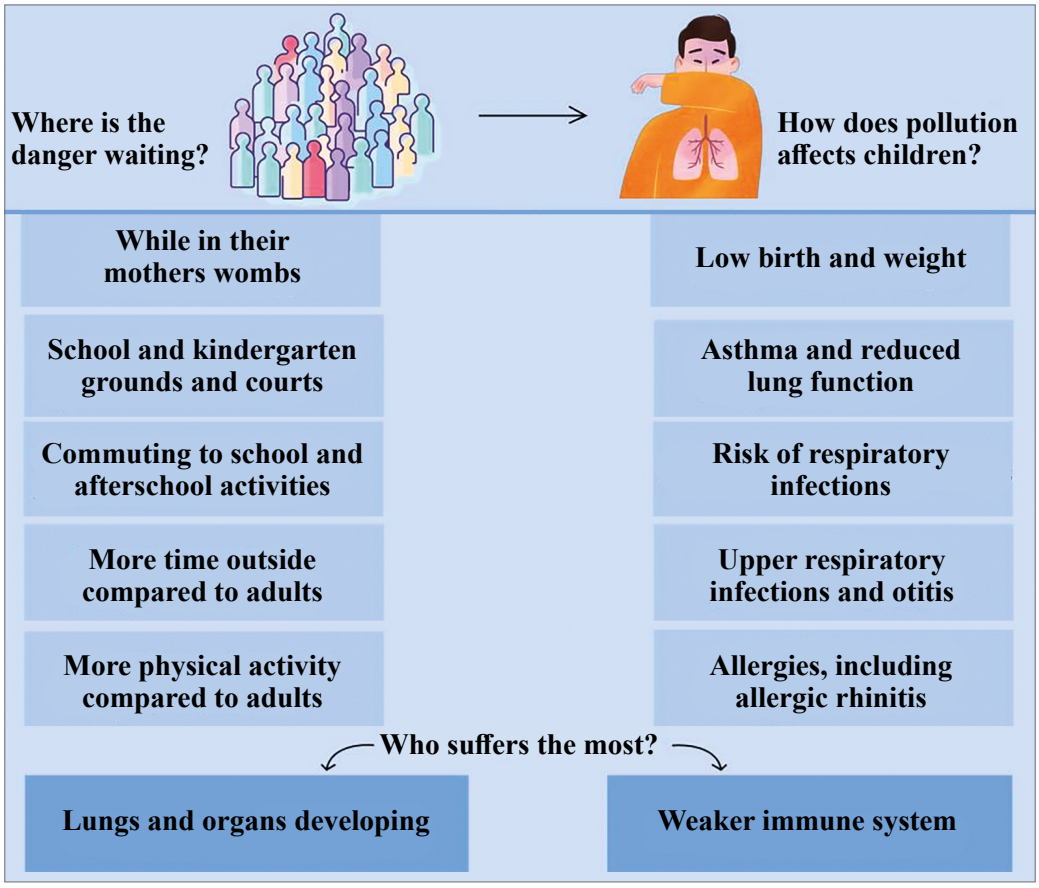

Figure 1. Infographic on the ways and impact of air pollution on children's health [the figure is created by the author].

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autism, retinopathy, fetal growth, and low birth weight [21].

Systematic reviews and meta-analyses have also found evidence of an association between pulmonary disease and adverse birth outcomes, including low birth weight, preterm birth, stillbirth, and low birth weight for gestational age (a condition known as «small for gestational age» or SGA) [22].

The above is confirmed by the EEA data, which shows that pregnant women exposed to high inhalation exposures to pollutants before birth had an increased risk of preterm birth and low birth weight during pregnancy. At the same time, Grippo et al. 2018; Zhang et al. 2021; Zhu et al. 2022 also associate an increased risk of spontaneous miscarriage and stillbirth with exposure to particulate matter [20]. In addition, a meta-analysis indicates a positive association between prenatal exposure to air pollution (PM_{10}, $PM_{2.5}$, nitrogen dioxide, and ozone) and the risk of autism spectrum disorder in children [23]. In later life, the above could increase the risk of various health problems for children.

After birth, polluted air also increases the risk of adverse health outcomes for children and adolescents, increasing the risk of respiratory infections, including acute lower respiratory tract infections, pneumonia, upper respiratory tract infections and otitis media (ear infections), and cardiovascular disease (in the future) [20].

Studies of Y.G. Antipkin and O.P. Volosovets indicate a direct relationship between the impact of emissions on the incidence and prevalence of pulmonary diseases among children (especially those aged 0-6 and 15-17 years inclusive) and the prevalence of bronchial asthma and diabetes in all age groups. At the same time, the environmental determinants of children's pulmonary diseases development, in particular bronchial asthma, can significantly burden and complicate the course of COVID-19 [24].

Today, asthma affects more than 9 % of children in the EU, and the risk of development and symptoms (from mild to very severe, even life-threatening) are linked to polluted air prolonged exposure (in particular PM_{10} and $PM_{2.5}$), as proven by epidemiological and clinical studies [20]. This is also confirmed by a team of scientists led by Gehring Uet al. who report an increased lifetime risk of children with asthma up to the age of almost 20 exposed to air pollution at an early age [25]. In addition, short-term increases in air pollution levels increase the risk of asthma hospitalization and emergency department visits for children [20].

According to the research conducted by Deng et al., a relationship was established between the development of bronchial asthma and allergic rhinitis for children whose mothers were exposed to polluted air during pregnancy. This is explained by various epigenetic mechanisms (DNA methylation), where various pollutants play an important role in the development of allergic diseases [26]. This is also evidenced by the research data presented in the publications of the US EPA, EEA, and UNICEF, which state that exacerbation and increased development of allergies, including allergic rhinitis (runny nose), eczema, and conjunctivitis (itchy eyes) for children caused by short-term exposure to polluted air [20], [3].

Scientists are also concerned about the impact of air pollution on pneumonia, which causes 22 % of all child deaths between the ages of 1 and 5. A study conducted by Stanford University showed that the incidence of pneumonia among children under 5 years of age increases by 3.2 % with each 10 $\mu g/m^3$ increase in $PM_{2.5}$ concentration. This difference equates to more than 200,000 additional cases of childhood pneumonia in Bangladesh each year and almost two million additional cases in South Asia. These increases are about twice as large as previous similar estimates of hospital admissions for pneumonia associated with increases in $PM_{2.5}$ and almost 10 times higher than estimates for outpatient visits [27].

At the same time, epidemiological studies have shown that exposure to $PM_{2.5}$, PM_{10}, and NO_2 air pollution can contribute to an increased risk of morbidity and progression of type 2 diabetes among children. This association may be more pronounced in overweight and obese children. The precise mechanism by which air pollution increases the incidence of type 2 diabetes remains to be determined. Possible mechanisms include systemic inflammation, oxidative stress,

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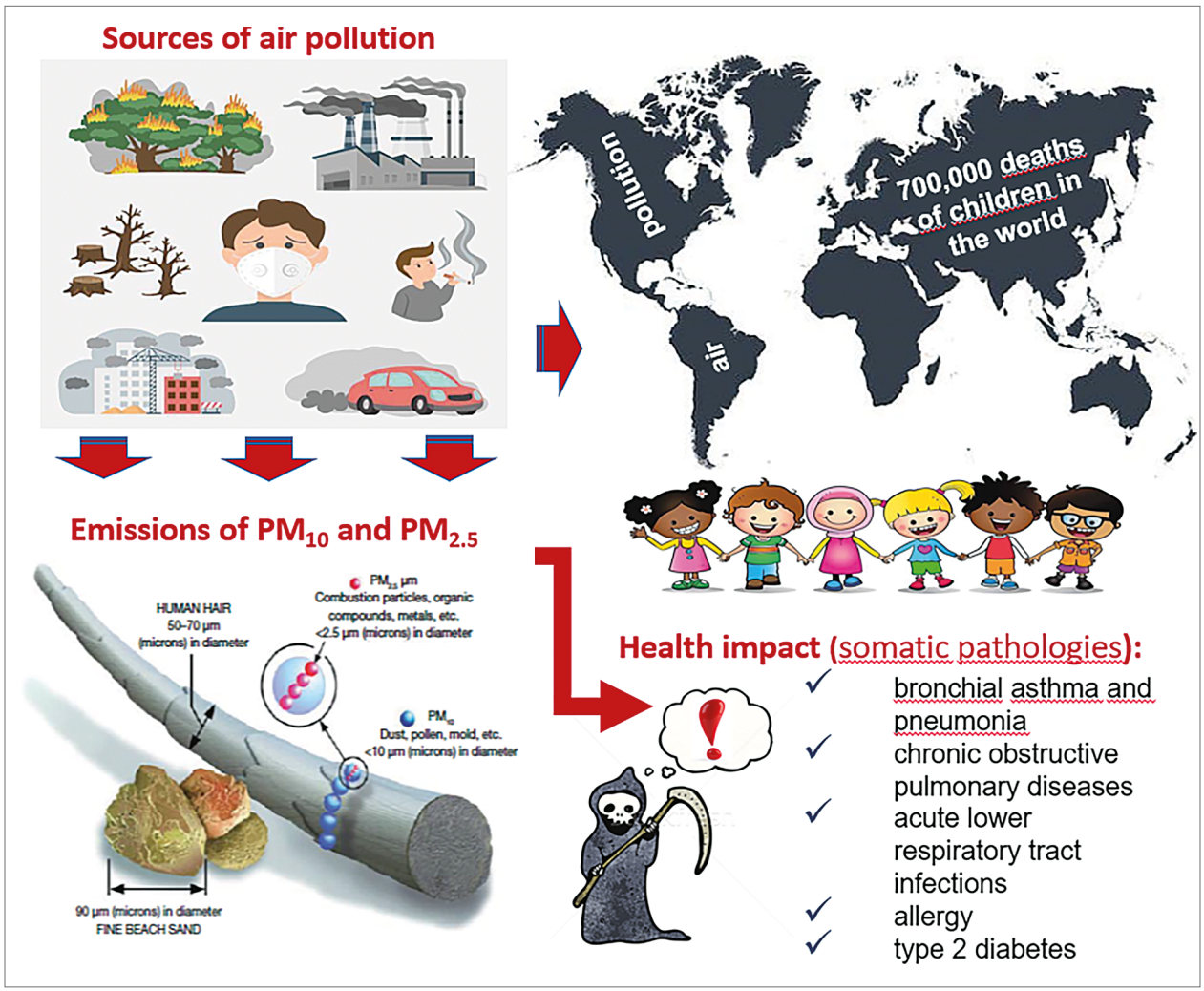

Figure 2. Impact of particulate matter (PM_{10} and $PM_{2.5}$) on the development of somatic pathologies in children [the figure is created by the author].

endoplasmic reticulum stress, mitochondrial dysfunction, and epigenetic changes [28, 29, 30].

Analyzing the above, atmospheric air pollution by PM_{10} and $PM_{2.5}$ from industrial enterprises and vehicles emissions, due to their microscopic nature and ability to penetrate the blood and lymph, leads to irreversible losses and morbidity in the child population (Fig. 2).

This, in turn, requires thorough epidemiological studies (including the search for biomarkers) to establish reliable links between the impact of air pollution and children's health to find the causes and mechanisms of their occurrence and preserve the health of future generations.

Conclusions

1. It has been determined that air pollution is the second risk factor for death among children under the age of five. Children are particularly vulnerable due to their higher levels of physical activity, an immature immune system, and underdeveloped respiratory system and metabolism, which result in increased lung ventilation and absorption of larger volumes of polluted air.

2. It was found that exposure to PM_{10}, $PM_{2.5}$ can lead to children's psychological complications, autism, and retinopathy; affect pregnancy and childbirth, provoking future health problems; increase the risk of bronchial asthma, respiratory infections, including acute lower respiratory tract infections, pneumonia, upper respiratory tract infections and otitis media (ear infections), allergic and cardiovascular diseases (in the future).

3. The above proves the urgency of conducting epidemiological studies to establish the relationship between the impact of air pollution (in parti-

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cular, PM_{10}, $PM_{2.5}$) and children's health to prevent social losses that may be caused to the state as a result of premature deaths and morbidity soon.

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Conflict of interest

There are no conflicts of interest in the presented work.

Consent to publication

All authors have read and approved the final version of the manuscript. All authors have agreed to publish this manuscript.

ORCID ID and authors contribution

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A – Work concept and design, B – Data collection and analysis, C – Responsibility for statistical analysis, D – Writing the article, E – Critical review, F – Final approval of article.

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Вплив забруднення атмосферного повітря твердими частками пилу (PM_{10} та $PM_{2.5}$) на розвиток соматичних патологій у дітей

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Анотація: *за даними Всесвітньої організації охорони здоров'я (ВООЗ) із забрудненням атмосферного повітря пов'язують 4,2 млн смертей на рік. Водночас його забруднення є другим фактором ризику смертності серед дітей у віці до п'яти років, що є причиною 700000 (15 % від усіх випадків) додаткових смертей у світі. Тому метою даного дослідження є*

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аналіз літературних даних, міжнародних і вітчизняних нормативно-методичних документів та інформаційних джерел для визначення ключових аспектів впливу твердих часток пилу (зокрема PM_{10} та $PM_{2.5}$) на розвиток соматичних патологій у дітей. Найбільшого занепокоєння у науковців та експертів в галузі охорони здоров'я викликають саме викиди твердих часток пилу (PM_{10}, $PM_{2.5}$), що є причиною 10 % соціальних втрат здоров'я українців, призводячи до 43 000 передчасних смертей. Особливо несприятливо їх вплив позначається на дітях через їх більшу фізичну активність, незрілу імунну систему, недостатньо розвинену систему легень та обмін речовин, що спричинює збільшення інтенсивності вентиляції легень та поглинання великого об'єму забрудненого повітря. У ході проведеного аналізу виявлено, що вплив PM_{10}, $PM_{2.5}$ може призводити до психологічних ускладнень у дітей, аутизму, ретинопатії; впливати на перебіг вагітності та пологи (самовільні викидні та мертвонародження), провокуючи у дітей в подальшому проблеми зі здоров'ям. Також підвищувати рівень поширеності бронхіальної астми, респіраторних інфекцій, включаючи гострі інфекції нижніх дихальних шляхів, пневмонію, інфекції верхніх дихальних шляхів і середній отит; та в майбутньому – серцево-судинних захворювань. Водночас існуючі дослідження стверджують про загострення та збільшення рівня розвитку алергії, включаючи алергічний риніт, екзему та кон'юнктивіт у дітей. Отже на підставі проаналізованих епідеміологічних та клінічних досліджень можна стверджувати про прямий достовірний зв'язок між впливом забруднення атмосферного повітря PM_{10}, $PM_{2.5}$ та збільшенням кількості захворювань органів дихання серед дітей (зокрема бронхіальною астмою та пневмонією). Особливої уваги, привертають дослідження присвячені підвищенню ризику захворюваності та прогресуванню цукрового діабету другого типу серед дитячого населення, зокрема пошуку причин і механізмів його виникнення. Вищесказане, вимагає проведення ґрунтовних епідеміологічних досліджень, що дуже обмежені в Україні.

Ключові слова: забруднення атмосферного повітря, тверді частки пилу (PM_{10}, $PM_{2.5}$), вплив забруднення атмосерного повітря на здоров'я дітей, соматичні патології, смертність.