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AIR POLLUTION AND CANCER RISKS: A REVIEW OF META-ANALYSES

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ABSTRACT

Relevance: *Air pollution, recognized by the World Health Organization as a global threat due to its contribution to the development of chronic and oncological diseases, is of particular concern in megacities such as Almaty, where pollution levels significantly exceed acceptable norms and pose a serious risk to vulnerable population groups.*

The study aimed to *systematically review meta-analyses focused on the effect of air pollution on the risk of developing various types of cancer, most relevant to the Republic of Kazakhstan.*

Methods: *This systematic review included publications from the PubMed, Web of Science, Scopus, Embase, and Cochrane Library databases from 2000 to February 18, 2025. Only meta-analyses were included to investigate the association of air pollutants (PM2.5, PM10, NO2, SO2, O3, VOCs, and others) with cancer. Relative risk (RR) parameters and pollutant concentrations were extracted for the analysis.*

Results: *The review revealed significant correlations between exposure to air pollutants and an in-creased risk of developing several cancers. The effect of pollutants on the risk of cancer is presented.*

Conclusion: *Air pollution is recognized as a significant risk factor for cancer and cancer mortality. In this regard, it is necessary to develop state and individual environmental measures, including the implementation of IT and hardware solutions for monitoring and improving air quality in residential and workspaces.*

Keywords: *air pollution, cancer, cancer risk, meta-analysis, PM2.5, NO2, Kazakhstan.*

Introduction: Today, the negative impact of air pollution on the respiratory and cardiovascular systems, as well as overall quality of life, is recognized as a significant problem in various geographical areas [1-3]. The connection between pollution and the development of cancer has also attracted the attention of researchers [4, 5]. According to the World Health Organization (WHO), air pollution causes millions of premature deaths every year, and its contribution to the development of chronic diseases and cancer pathologies is recognized as a global threat [6].

According to a UNICEF policy brief [7], air pollution is the main environmental health risk for children. Young children are particularly at risk of death and illness from air pollution [7]. According to the Institute for Health Metrics and Evaluation (IHME, UK), in 2021, 6,441 child and adolescent deaths from air pollution-related causes were recorded in 23 countries and territories in Europe and Central Asia, and the vast majority (85%) died in the first year of life [8].

Among the major cities with high levels of pollution, Almaty, Kazakhstan's largest metropolis, holds a special place. The city suffers from intense emissions from industrial enterprises, vehicle exhaust gases, and unfavorable natural conditions, including its geographical location in a basin that limits natural air ventilation [9]. According to environmental reports, concentrations of pollutants such as PM2.5, PM10, nitrogen dioxide (NO2), and sulfur dioxide (SO2) in Almaty often exceed the maximum permissible levels [9, 10]. According to IQAir [11], a global air quality monitoring platform, PM 2.5 concentrations in Almaty regularly exceed WHO ambient air quality guidelines by 17 times during the winter months [11]. Additionally, according to a new World Bank study, cleaner residential heating is one of the key factors in reducing air pollution in Kazakhstan's cities [12].

The growing scale of the air pollution problem necessitates not only environmental action but also a comprehensive understanding of its health implications. This article reviews the results of meta-analyses devoted to the impact of air pollution on the risk of various types of cancer.

The study aimed to systematically review meta-analyses focused on the effect of air pollution on the risk of developing various types of cancer, most relevant to the Republic of Kazakhstan.

Materials and methods:

Data sources and search strategy. This systematic review comprised articles from the largest medical and environmental databases, including PubMed, Web of Science, Scopus, Embase, and the Cochrane Library. The

search was conducted for the period from 2015 to 2025. The following keywords and their combinations were used: "air pollution", "carcinogenesis", "cancer risk", "meta-analysis", "particulate matter (PM2.5, PM10)", "volatile organic compounds (VOCs)", "nitrogen dioxide (NO2)", "ozone (O3)". The review included only meta-analyses that: (1) were published in peer-reviewed journals, (2) contained data on the relationship between air pollutants (PM2.5, PM10, NO2, SO2, O3, volatile organic compounds (VOCs) and others) with the risks of developing cancer of the most common types of cancer in the Republic of Kazakhstan.

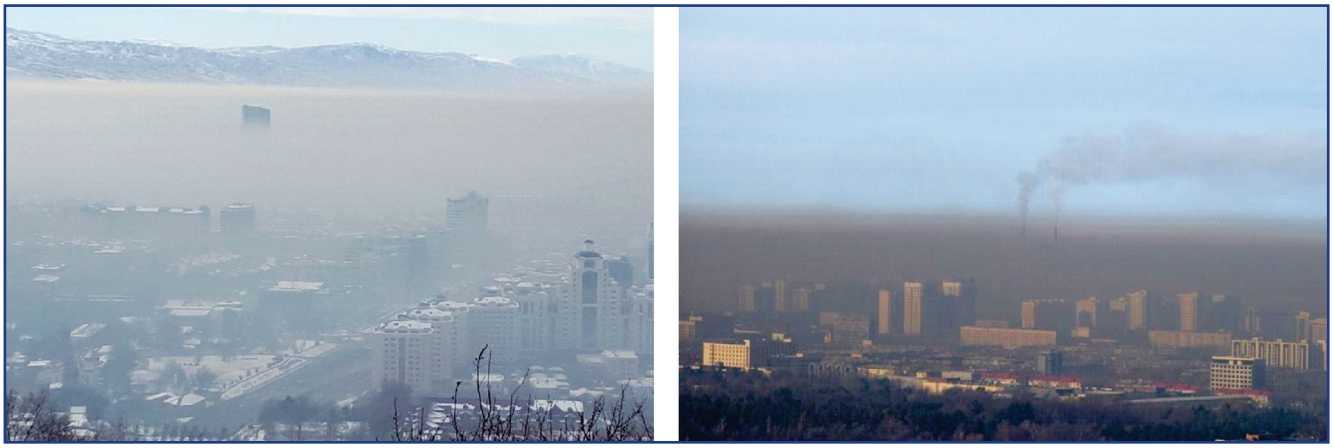

Figure 1 – Typical state of the air basin in Almaty in winter (left) and autumn (right) periods

Study selection process. All retrieved publications were uploaded to the EndNote bibliography manager. Duplicate records were removed. Two independent researchers performed the initial screening based on titles and abstracts. Full texts of the retrieved articles were reviewed to determine whether they met the inclusion criteria. The following parameters were extracted for data analysis: (1) relative risk (RR), odds ratio (OR), or hazard ratio (HR) for developing cancer, (2) air pollution levels in the analyzed studies.

Ethical aspects. Since the work was based on the analysis of already published data, ethical approval was not required. All studies included in the review met the ethical standards set for primary data.

Results:

Breast cancer and traffic-related air pollution. Traffic-related air pollution increases the risk of breast cancer by 1.5% for every 10 μg/m3 increase in NO2 exposure [13]. Additionally, combustion-related nitric oxide (NO) is oxidized in air to form NO2, which plays a role in several stages of cancer, including angiogenesis, apoptosis, cell cycle progression, invasion, and metastasis [14-16].

A systematic review by J. Tippila et al. included 25 parallel studies on the association between air pollution and breast cancer, with a primary focus on PM2.5, PM10, and NO2 [17]. In a study by JY Ou et al. [18], in a group of young patients under 39 years of age, PM2.5 concentrations ≥ 12 μg/m^3 were associated with increased breast cancer mortality, HR for 5 years = 1.50 (95% CI from 1.29 to 1.74), HR for 10 years = 1.30 (95% CI from 1.13 to 1.50) [18]. A study by A. Amadou et al. (2021) showed that long-term exposure to benzo(a)pyrene in the ambient air is associated with an increased risk of developing breast cancer - for every 1 interquartile range (IQR) increase in benzo[a]pyrene concentration (1.42 ng/m^3), there was an increase in the OR=1.15 (95% CI: from 1.04 to 1.27), higher rates were observed in women who had experienced the menopausal transition and in patients with hormone-positive tumors [19].

Proximity to roads is also a danger for children – one study reported a borderline association (HR=1.4; 95% CI: 1.0-1.9) between breast cancer risk and childhood proximity to a road with characteristics of high exposure to traffic-related pollutants. The influencing factors included (1) proximity, (2) presence of a median/barrier, (3) multiple lanes, and (4) heavy traffic [20].

Lung cancer: Pooled estimates showed that NO2, EC, and PM2.5 were associated with mortality from all causes, cardiovascular diseases, coronary heart disease, respiratory diseases, and lung cancer (RR=1.04; 95% CI: 1.01-1.07) [21].

The study by B. Brunekreef describes the connections between long-term effect of four pollutants (PM2.5, NO2, BC, and O3) on health. The researchers found significant positive associations between PM2.5, NO2, and BC and death from natural causes, respiratory, cardiovascular diseases and lung cancer, with moderate to high heterogeneity between cohorts – for lung cancer, an increase in HR was found only for PM 2.5, HR 1.13 (95 % CI: 1.05-1.23) [22].

A meta-analysis by Ramamoorthy et al. [23] involved 61 studies, including 53 cohort studies and 8 case-control studies. PM 2.5 was the exposure pollutant in half (55.5%) of the studies, and lung cancer was the most commonly studied cancer, in 59% of the studies [23]. A pooled analysis of exposure from cohort and case-control stud-

ies and cancer incidence showed a significant association, RR=1.04 (95% CI: 1.02-1.05). Significant associations were observed between exposure to pollutants such as PM2.5 (RR=1.08; 95% CI: 1.04-1.12) and nitrogen dioxide (NO2) (RR=1.03; 95% CI: 1.01-1.05) and the incidence of lung cancer. The association between air pollutant exposure and cancer mortality showed a significant association (RR=1.08; 95% CI: 1.07-1.10). Among the four pollutants, PM2.5 (RR=1.15; 95% CI: 1.08-1.22) and NO2 (RR=1.05; 95% CI: 1.02-1.08) were significantly associated with lung cancer mortality. The study confirms the association between air pollution exposure and lung cancer incidence and mortality [23].

JS meta-analysis by Pyo et al. included 19 studies that assessed exposure to PM2.5 and PM10 [24].

The analysis showed that the incidence of lung cancer was significantly increased by PM2.5 exposure (RR=1.172; 95% CI: 1.002-1.371). All-cause mortality and lung cancer mortality were significantly increased by PM 2.5 exposure (HR=1.143; 95% CI: 1.011-1.291 and HR=1.144; 95% CI: 1.002-1.307, respectively) [6].

Thus, the above meta-analyses confirm that air pollution is a significant risk factor for the development of a number of cancers. It should also be taken into account in terms of long-term exposure and the effect on rare cancers.

Colorectal cancer. A meta-analysis of seven observational studies confirmed an association between PM2.5 exposure (per 10 μg/m^3 increment) and an increased risk of colorectal cancer (RR=1.42; 95% CI: 1.12-1.79). At the same time, a higher Air Pollutants Exposure Score, proposed by the study working group, was associated with an increased risk of colorectal cancer (RR=1.03; 95% CI: 1.01-1.06) and worse survival (RR=1.13; 95% CI: 1.03-1.23), especially among participants with insufficient physical activity and ever-smoking [25].

A meta-analysis of 30 cohort studies found that a 10 μg/m^3 increase in PM2.5, PM10, and nitrogen dioxide (NO2) levels was associated with an increased odds of cancer mortality of 17% (95% CI: 11-24%), 9% (95% CI: 4-14%), and 6% (95% CI: 2-10%), respectively. In particular, a 6.5 parts per billion (ppb) increase in NO2 was associated with an increased odds of colorectal cancer mortality of 6% (95% CI: 2-10%) [26].

A meta-analysis including 13 studies found that PM2.5 exposure was associated with a 12% (95% CI: 1-24%) increased risk of developing gastrointestinal cancer. The largest associations were found for liver cancer, where the risk increased by 31% (95% CI: 7-56%), and for colorectal cancer, where the risk increased by 35% (95% CI: 8-62%) [27].

A meta-analysis by P. Fu et al. found an association between PM2.5 exposure and an 18% (95% CI: 9-28%) increase in the risk of colorectal cancer incidence and a 21% (95% CI: 9-35%) increase in mortality from it [28].

Discussion: Environmental problems in Kazakhstan are linked to urban growth, the use of coal and oil for electricity and heating, and the mining industry [29]. The intensive development of natural resources, often without considering their environmental impact, inevitably leads to land and soil pollution [29]. Worth noting, Almaty, the largest city in Kazakhstan, has one of the highest levels of air pollution [30]. The main sources of pollution are emissions from industry, motor vehicles, and heating systems [9]. The city's geographical location in a basin at the foot of the mountains significantly limits natural air ventilation, exacerbating the situation with air pollution [9-11].

In winter, the concentration of pollutants such as PM2.5, PM10, NO2, and SO2 can exceed the maximum permissible levels by 10 to 17 times [11]. This poses a direct threat to the health of city residents, increasing the risk of developing cancer, respiratory, and cardiovascular diseases. It should be noted that current scientific work focuses on the impact of pollution on cancer incidence, but does not assess the condition of cancer patients after cancer-related interventions. This direction can be a point of growth in assessing outcomes after interventions, as well as in comparing the effectiveness of various interventions in patients across regions with differing environmental conditions.

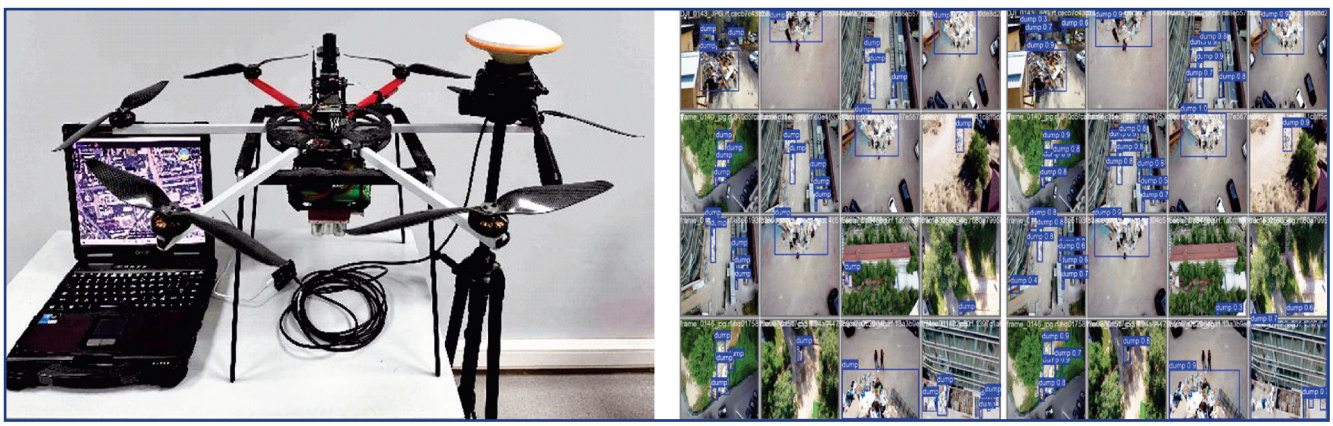

Figure 2 – UAVs developed by the research group and an example of analysis of city pollution by solid household waste using artificial intelligence

Given the risks described, it is necessary to take proactive measures to minimize the impact of air pollution on public health. This includes both government initiatives to adopt environmentally friendly technologies and enhance air quality monitoring, as well as individual efforts, such as utilizing modern software and engineering solutions to improve air quality in residential and workspaces. Environmental education programs, the introduction of energy-efficient technologies, and the development of public transport can also become an important part of the risk mitigation strategy. One of the areas that the CUES scientific group is proactively pursuing is the development of monitoring the city's environmental status using uncrewed aerial vehicles (UAVs) [29]. The introduction of UAVs will help to better monitor the environmental status and assess the danger of individual areas of the city, and, together with other technologies, provide a contour for assessing personal environmental safety and identifying measures to reduce risks.

Thus, decisive actions and coordination of efforts at the state, public, and individual levels are necessary to improve the environmental situation and reduce the negative impact of air pollution on public health in Almaty and other cities with similar geographical conditions.

Conclusion: The above material suggests the need to develop environmental measures to counteract air pollution that affects oncological diseases. It is necessary to conduct educational activities among oncologists to increase awareness of the risks associated with environmental pollution.

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АҢДАТПА

АУАНЫҢ ЛАСТАНУЫ ЖӘНЕ ОНКОЛОГИЯЛЫҚ АУРУЛАРДЫҢ ДАМУ ҚАУПІ: МЕТА-АНАЛИЗДЕРГЕ ШОЛУ

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Өзектілігі: *Созылмалы және онкологиялық аурулардың дамуына әсері үшін Дүниежүзілік денсаулық сақтау ұйымы тарапынан жаһандық қауіп ретінде танылған ауаның ластануы, ластану деңгейі рұқсат етілген шектерден айтарлықтай асып түсетін және әсіресе осал халық топтары үшін қауіп төндіретін Алматы секілді мегаполистерде ерекше алаңдаушылық тудырады.*

Зерттеудің мақсаты *– бұл зерттеудің мақсаты Ауаның ластануының Қазақстан Республикасы үшін негұрлым өзекті болып табылатын онкологиялық аурулардың әртүрлі түрлерінің даму қаупіне әсеріне арналған мета-талдауларға жүйелі шолу болып табылады.*

Әдістері: *Жүйелі шолу PubMed, Web of Science, Scopus, Embase және Cochrane Library дерекқорларындағы 2000 жылдан 2025 жылғы 18 ақпанға дейінгі кезеңде жарияланған еңбектер негізінде жасалды. Ауаны ластаушы заттардың (PM2.5, PM10, NO2, SO2, O3, VOCs және т.б.) қатерлі ісікпен байланысын зерттейтін мета-талдаулар ғана қамтылды. Талдау үшін салыстырмалы тәуекел параметрлері (RR) және ластаушы заттардың концентрациясы алынды.*

Нәтижелері: *Шолу ауаны ластаушы заттардың әсері мен бірқатар онкологиялық аурулардың даму қаупінің жоғарылауы арасындағы айтарлықтай корреляцияны анықтады. Ластаушы заттардың қатерлі ісік қаупіне әсері ұсынылған.*

Қорытынды: *Ауаның ластануы қатерлі ісік пен қатерлі ісік ауруынан болатын өлім-жітімнің маңызды қауіп факторы ретінде танылды. Осыған байланысты тұрғын және жұмыс орындарындағы ауа сапасын бақылау және жақсарту үшін IT - және hardware шешімдерін енгізуді қоса алғанда, мемлекеттік және жеке экологиялық шараларды өзірлеу талап етіледі.*

Түйінді сөздер: *ауаның ластануы, онкологиялық аурулар, қатерлі ісік даму қаупі, мета-талдау, PM2.5, No2, Қазақстан.*

АННОТАЦИЯ

ЗАГРЯЗНЕНИЕ ВОЗДУХА И РИСКИ РАЗВИТИЯ ОНКОЛОГИЧЕСКИХ ЗАБОЛЕВАНИЙ: ОБЗОР МЕТА-АНАЛИЗОВ

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Актуальность: *Загрязнение воздуха, признанное Всемирной организацией здравоохранения глобальной угрозой из-за его вклада в развитие хронических и онкологических заболеваний, вызывает особую тревогу в мегаполисах вроде Алматы, где его уровни значительно превышают нормы и особенно опасны для уязвимых групп населения.*

Цель исследования *– систематический обзор мета-анализов, посвященных влиянию загрязнения воздуха на риск развития различных видов онкологических заболеваний, наиболее актуальных для Республики Казахстан.*

Методы: *Систематический обзор был выполнен на основе публикаций из баз данных PubMed, Web of Science, Scopus, Embase и Cochrane Library за период с 2015 по 2025 годы. Включались только мета-анализы, исследующие связь загрязнителей воздуха (PM2,5, PM10, NO2, SO2, O3 и других) с онкологическими заболеваниями. Для анализа извлекались параметры относительного риска (RR) и концентрации загрязняющих веществ.*

Результаты: *Обзор выявил значительные корреляции между воздействием загрязнителей воздуха и повышенным риском развития ряда онкологических заболеваний. Представлено влияние загрязнителей на риск онкологических заболеваний.*

Заключение: *Загрязнение воздуха признано значимым фактором риска развития рака и смертности от онкологических заболеваний. В связи с этим требуется разработка государственных и индивидуальных экологических мер, включая внедрение программных и инженерных решений для мониторинга и улучшения качества воздуха в жилых и рабочих помещениях.*

Ключевые слова: *загрязнение воздуха, онкологические заболевания, риск развития рака, мета-анализ, PM2,5, NO2, Казахстан.*

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