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Mini-review

Particulate matter ($PM_{2.5}$ and PM_{10}): current concepts and toxicological assessment

Zhanat Baigazinov[1], Yelena Polivkina[2]*, Nurlan Mukhamediyarov[1,3], Kassym Zhumadilov[4], Sayan Salmenbayev[2], Laura Kenzhina[2]

[1]Park of Nuclear Technologies, Kurchatov, Kazakhstan;
e-baygazinov@pnt.kz, mukhamediyarov@pnt.kz, aktaev@mail.ru
[2]Institute of Radiation Safety and Ecology of RSE NNC RK, Kurchatov, Kazakhstan; polivkina.elena75@gmail.com, salmenbayev@gmail.com
[3]Scientific Research Center "EventumLab", Semey, Kazakhstan;
mukhamediyarov@pnt.kz
[4]L.N. Gumilyov Eurasian National University, Astana, Kazakhstan;
zhumadilovk@gmil.com
*Correspondence: polivkina.elena75@gmail.com

Abstract. One of the current issues of atmospheric pollution is particulate matter (PM). PM can be of both natural and anthropogenic origin. This review summarizes the current concepts of PM, as well as approaches to their classification and toxicological properties. The most significant and dangerous for the environment are particles with aerodynamic sizes of 2.5 and 10 micrometers ($PM_{2.5}$ and PM_{10}). The main sources of PM include construction, mining, fuel and energy enterprises, as well as road transport. The article provides a comparative analysis of the current environmental standards for $PM_{2.5\text{-}10}$ in Kazakhstan, the Russian Federation, the EU, China, and the USA. In the EU, China, and the USA, there are no single maximum permissible concentration (MPC) limits for $PM_{2.5}$, as is the case in the Russian Federation and Kazakhstan. However, the EU and USA have stricter average daily and annual MPC limits for $PM_{2.5\text{-}10}$. Analysis of data on the continuous exposure to $PM_{2.5\text{-}10}$ in the EU, China, and the USA has allowed us to identify the main risk groups associated with an increased risk of cardiovascular and respiratory diseases, as well as mortality. The complexity in assessing the toxic effects of $PM_{2.5\text{-}10}$ stems from the significant variability and instability in their chemical composition, morphology, and dispersion properties. The main strategy for managing risks and improving public health outcomes is to reduce levels of $PM_{2.5\text{-}10}$ pollution. In Kazakhstan, government measures to monitor and control the concentration of PM aim to reduce air pollution, but they have not been sufficiently effective in addressing public health risks.

Keywords: atmospheric air; particulate matter; $PM_{2.5}$; PM_{10}; toxicological assessment; regulation; health risks.

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1. Introduction

Atmospheric air is one of the main and vital components of the environment. Over the past decades, suspended particles (abbreviated as particulate matter, or PM) have come to the forefront, which are one of the six most significant criteria for air pollutants according to the Environmental Protection Agency (EPA) definition (Particulate Matter (PM) Pollution, 2024). The largest contributors to air pollution by PM are agriculture, energy, transportation, industry, commercial sectors, and waste disposal, as well as burning solid fuels for municipal purposes, and even tobacco smoke (Strelyaeva et al., 2014; Putaud et al., 2010; Li et al., 2015). PM is a widespread air pollutant that includes a mixture of organic and inorganic substances, with a wide range of spatial and temporal variations in their physical and chemical properties (Khan et al., 2010; Jiang et al., 2018; Kumar et al., 2025). The air pollution caused by suspended particles has many complex consequences for the environment and public health. If other pollutants are identified by their chemical composition, PM is a general term for all suspended particles in the air, regardless of their molecular composition. Due to their small size and weight, PM can be carried by wind over considerable distances and deposited on Earth's surface or in reservoirs (Khan et al., 2010; Jiang et al., 2018; Kumar et al., 2025; Finlayson-Pitts et al., 2025; Seinfeld et al., 2006). Adverse effects on public health and biota from suspended particles are associated with their aerodynamic size, which determines their migratory and penetrating abilities (Pavlík et al., 2012; Kim et al., 2015; Magnani et al., 2016; Rajper et al., 2018; Fatkhutdinova et al., 2021; Pu et al., 2022). The greatest danger to the biosphere is represented by $PM_{2.5}$ particles (Khan et al., 2010; Strelyaeva et al., 2014; Kumar et al., 2025).

A significant number of studies have been conducted to investigate the influence of meteorological factors on particle migration (Katsouyanni et al., 2001; Li et al., 2015; Cao et al., 2013; Xu et al, 2017; Jiang et al., 2018) and the influence of PM size on cumulative effects (Valavanidis et al., 2010; Khan et al., 2010; Jiang et al., 2018; Kumar et al., 2025). Also, in literature, there are studies on the impact of particulate matter on urban air pollution and its negative impact on public health, flora, fauna and soil (Xu et al., 2017; Zagorodnov et al., 2018; World health statistics, 2018; Valavanidis et al., 2010; Anderson et al., 2012; Zheng et al., 2015; Bennett et al., 2019; Tokbergenov et al., 2022; Ghobakhloo et al., 2023; Ning et al., 2024; Kumar et al., 2025; Relić et al., 2023; Liu et al.,2019; Liu et al., 2022; Li et al., 2015). Numerous PM studies have been conducted in cities in China, Europe and the United States.

In this aspect, the purpose of the review is to summarize knowledge about PM in terms of its origin, physicochemical and toxicological properties, classification, problems of environmental standards and assessment of public health effects. The review also includes research data from Kazakhstan and other countries of the Commonwealth of Independent States (CIS).

2. Current concepts and toxicological effects of particle matter

The descriptive review was carried out in accordance with the recommendations of PRISMA (Matthew et al., 2021). The research was carried out in the spring and summer of 2025 in English and Russian independently by two people in the databases PubMed, Scopus, Google Scholar, and the library without limitation of the publication period. The search used keywords related to the subject of the study – "suspended particles" or "particulate matter" (PM) and atmospheric air pollution by PM, and morbidity of the population due to air pollution by PM. In addition, the literature lists of publications selected for a descriptive review were also reviewed.

2.1. The concept of "PM" and its classification

The term "suspended particles" refers to solid or liquid substances dispersed in the gas phase. To denote them in short form, the abbreviation "PM" is used – a derivative of the English phrase "particulate matter". As a rule, in meteorology, atmospheric physics and chemical ecology, PM mainly refers to solid particles (Anderson et al., 2012; Putaud et al., 2010; Ghobakhloo et al., 2023). PM is formed as a result of various processes such as grinding, condensation and drying of solutions, for example, marine dust, as well as chemical reactions. These particles become suspended under the influence of air or gas flows and form what we commonly call "particulate matter" (Strelyaeva et al., 2014).

For the purposes of air quality regulation, PM is determined by their degree of dispersion, namely their aerodynamic size. Anthropogenic gas emissions include solid particles ranging in size from 0.5 to 200 microns.

Table 1 shows the main differences between PM in a number of characteristics, for example, origin, size, shape and method of generation.

Table 1. Classifications of PM

Criteria	Name	Examples
By origin (Ghobakhloo et al., 2023)		
Natural	Natural PM	Sandstorms, rock weathering, volcanic activity, evaporation from the surfaces of seas and oceans, soil erosion, forest fires, steppe fires and peat fires, dust-like substances of plant origin, plant pollen, microorganisms and fungal spores
Artificial	Man-made PM	Emissions from fuel combustion, fuel and energy complex, transport, during road and construction work, mining, production of building materials, and smelting
Primary	Primary PM	They directly enter the air from both natural and man-made sources
Secondary	Secondary PM	Already formed in the atmosphere as a result of chemical transformations of gaseous substances: SO_2, NO_X, NH_3, volatile organic compounds (VOC). Basically, secondary PM is of anthropogenic origin
By size (Seinfeld et al., 2006; Putaud et al., 2010)		
Finely dispersed (d < 0.25 microns)	Finely dispersed, submicron aerosols	smoke particles, soot particles, smog
Medium - dispersed (0.25 microns < d < 10 microns)	Microscopic aerosols	smoke particles, soot particles
Coarse- dispersed (d > 10 microns)	Giant aerosols	dust storms
Isometric	Spherical	soot and silica particles
Fibrous	Chained	asbestos, glass, metal and vegetable dust
By the generation way (Ivlev et al., 2000)		
Dispersional	Dispersional	They are formed as a result of the mechanical dispersion of solids and the subsequent dispersion of fine particles in the air. As a rule, such particles have a relatively large size (> 10 microns) and an irregular shape.
Condensation	Condensation	They are formed during the combustion or sublimation of substances (particles of soot, for example), as well as a result of photochemical reactions in the atmosphere. As a rule, these are fine particles with a diameter of < 0.25 microns.

The most important property of PM is the high specific surface area of the dispersed phase, reaching hundreds of square meters per gram of dispersed substance, and a significant amount of time spent in the air (Spurny et al., 1964). PM with a diameter ranging from 1 to 10 microns can remain airborne for several days. The hover time for particles smaller than 1 micron is 10 to 20 days. PMs smaller than 0.1 micron do not precipitate at all because their speed of Brownian motion is faster than the rate of deposition (Spurny et al., 1964).

When it comes to solid particles, the number to the right of PM indicates the aerodynamic diameter in microns. The concentration of PM is usually determined in weight, i.e., the number of micrograms per cubic meter (μg/m^3). So, depending on aerodynamic size, PM can be conventionally divided into two categories: coarse dust (particles less than 10 μm) and fine dust (particles smaller than 2.5 μm) (Valavanidis et al., 2010). Also, according to the technical definition, $PM_{2.5}$ is included in PM_{10} (which covers all particles less than 10 microns in diameter).

To make it clear, these dimensions are much smaller than a human hair (Figure 1).

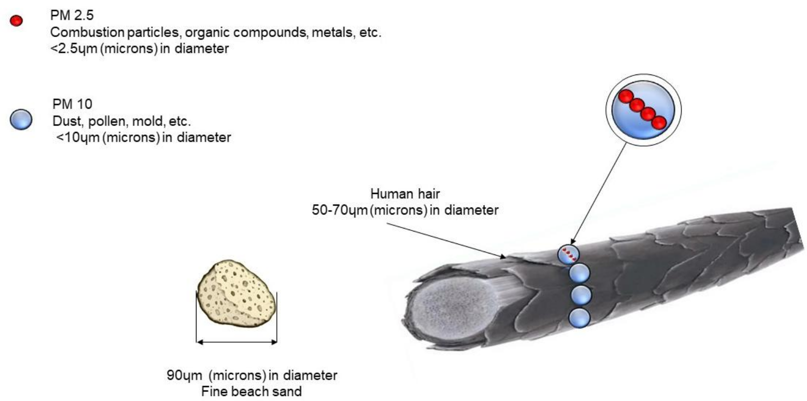

Figure 1. Dimensions of $PM_{2.5}$ and PM_{10}

In addition to coarse and fine dust, when discussing PM, one may encounter references to the smallest ultrafine dust (PM_1, $PM_{0.1}$, etc.), which has an aerodynamic diameter of 1 micron or less. PM0.1 is referred to as a nanoparticle. Particles less than 10 microns in size have the greatest environmental significance, as they are virtually not captured by common industrial cyclones. Unlike larger particles, which are captured up to 90-95% (Fatkhutdinova et al., 2021). It is these fine particles that easily penetrate into the lowest parts of the lungs with inhaled air and have a negative impact on human health.

2.2. Sources of PM entering the atmosphere

PM can have both natural and anthropogenic origins (Table 1). There are many natural sources of PM pollution, including dust storms, forest fires, wind erosion, sea spray and even plant pollen (Seinfeld et al., 2006; Ivlev, 1982; Friedlander, 2000; Ivlev, 2013; Brines et al., 2015). Thus, smoke from forest fires contains a lot of solid particles, mainly $PM_{2.5}$ (Strelyaeva et al., 2014; Ghobakhloo et al., 2023). In large areas of the arid zones of Asia and Africa, droughts and intensive exploitation of pastures lead to a reduction in vegetation cover and the removal of dust particles from it. As a result of sand and dust storms, dust can rise high into the atmosphere and travel long distances, often moving even across oceans. Such storms annually transport an average of half a billion tons of minerals and nutrients to the oceans, which, when coming from the atmosphere, can affect primary production in the ocean, including coastal areas. This process triggers biogeochemical cycles in the oceans, including circulation of carbon, nitrogen, sulfur, phosphorus, and silicon (Ivlev, 1982; Finlayson-Pitts and Pitts, 2000). In some parts of Africa and the Middle East, most of the particle pollution is caused by dust brought in from arid areas (Ivlev, 1982). In Russian cities located in the Asian part of the country, air pollution caused by microparticles comes from transporting air masses from deserts in Africa and Asia (Varenik et al., 2021)

The most significant contribution to the atmospheric pollution of modern cities is made by emissions from motor vehicles and power plants. Also, sources of PM entering the urban atmosphere include the construction industry (production of cement, ceramics, bricks), the metallurgical industry, and the transshipment of bulk cargo (Harrison et al., 2001; Khan et al., 2010; Crilley et al., 2017; Hao et al., 2019; Ghobakhloo et al., 2023). The machine-building enterprises release significant amounts of dust in areas where materials are mechanically processed, welded and cut. At ferrous metallurgical enterprises, sintering, foundries, blast furnaces, steelmaking, and rolling are the main sources of dust emissions. In mining operations, the most dust is produced during ore transportation, drying, and flotation. The production of building materials such as mortars, concrete, and hollow slabs also emits dust during preparation and storage in open warehouses (Zagorodnov, 2018). In emissions from machine-building enterprises, the content of fine particles of $PM_{2.5}$ and PM_{10} was 13% and 40%; ferrous metallurgy was 79% and 84%; non-ferrous metallurgy 43% and 98%; mining industry 21% and 59%, respectively (Zagorodnov, 2018).

In 2023, industrial combustion was the main source of PM emissions in the United Kingdom (UK). Emissions from industrial processes and product use accounted for 16% of total $PM_{2.5}$ emissions and 38% of all PM_{10} emissions. Road transport accounted for 21% and 18%, respectively, of $PM_{2.5}$ (Emissions of air pollutants, 2025).

Studies of the concentration and spatial distribution of PM in Belarus have shown that industrial production, household sector, and road transport are the main contributors to the formation of high concentrations of PM_{10} halos in atmospheric air (Kakareka et al., 2021). At the same time, the highest concentrations of $PM_{2.5}$ and $PM_{0.1}$ are formed near roads, particularly road sides and traffic intersections (Kumar et al., 2020).

Air pollution in Kazakhstan is caused by various factors and poses a serious threat to public health. The atmospheric air in many cities of Kazakhstan is polluted due to the following main reasons: extraction and processing of mineral resources, oil and gas extraction, operation of motor vehicles, and emissions from industrial enterprises (Kenessary et al., 2019).

Almaty is one of the most polluted cities in Kazakhstan and Central Asia. The average winter concentration of $PM_{2.5}$ in Almaty is 94.0 micrograms per cubic meter (Tursumbayeva et al., 2022). In 2024, in Almaty, the total volume of pollutants emitted into the atmosphere from stationary sources was 189 thousand tons. Of this, 60% was accounted for by motor vehicles, 27.5% by industrial enterprises, and 11% by housing and the private sector. The remaining 0.74%, or 0.076%, was emitted by stationary sources of small and medium-sized businesses and construction facilities. The average annual concentration of $PM_{2.5}$ was 24.1 micrograms per cubic meter, which was 4.8 times higher than the WHO norm (Kurmangazinova, 2025).

In 2016, WHO published a report on the content of PM_{10} and $PM_{2.5}$ in atmospheric air in 2975 cities around the world. The report WHO indicates that the quality of atmospheric air is dependent on the socio-economic status of a country. Concentrations of suspended particles were significantly higher in cities in the Asian region (India, Pakistan, Afghanistan, China and Mongolia) and in the Eastern Mediterranean region (World health statistics, 2018).

2.3. Toxicological characteristics of PM and their effect on public health

Unlike the well-studied gaseous pollutants of atmospheric air, PM have such special properties that are determined by the course of physicochemical processes in the atmosphere. As for $PM_{2.5}$ and PM_{10}, primary and secondary particles are isolated. Primary particles enter the air ready-made, and secondary particles form directly in the air as a result of various chemical reactions. Most $PM_{2.5}$ and PM_{10} particles are sorbents that can adsorb toxic compounds, leading to particles with harmful additives. The World Health Organization (WHO) classified PM as a priority air pollutant, along with nitrogen oxides, ozone, sulfur oxides, formaldehyde, and polycyclic aromatic hydrocarbon (World health statistics, 2018).

The suspended particles have a high specific surface area. The most common chemical components of particulate matter (PM) include inorganic anions (such as sulfates, nitrates, and chlorides), cations (like sodium, potassium, calcium, and magnesium), organic and elemental carbon, ammonia, minerals from the Earth's crust, soot particles, rubber, sand, asphalt, water particles, the smallest droplets of liquid (also known as aerosol pollution), and heavy metals and their compounds (Crilley et al., 2017; Kumar et al., 2020). PM may also contain biological components such as microorganisms (mold spores, bacteria, and dust mites), microbial waste products, and pollen. It is worth noting that most of these components are allergens (Kumar et al., 2020; Khan et al., 2010).

The diversity of the chemical composition and size of PM, as well as the unpredictability of physicochemical processes on their surfaces, is the reason for difficulties encountered in assessing toxicity of suspended particles. The toxicological assessment of $PM_{2.5}$ and PM_{10} involves numerous mechanisms, such as inflammatory processes and oxidative stress. This condition is a problem in the study of the effects of $PM_{2.5}$ and PM_{10} on humans and the environment. Besides, it is due to the considerable time spent in the air, which can be from several hours to several days or more. As for PM_1 and $PM_{0.1}$, there is still no clear understanding of their short- and long-term effects on public health.

As a result of numerous studies conducted over the past decades worldwide on the negative effects of suspended particles on public health, it has been statistically reliably established that their toxicity is determined by both their chemical composition and aerodynamic dimensions (Anderson et al., 2012; Fatkhutdinova et al., 2021; Xu et al., 2017). PM_{10} and $PM_{2.5}$ particles are considered to be respiratory, as their diameter allows them to enter the thoracic part of the human respiratory system and then the bloodstream (Pope, 2000; Pope et al., 2006). The depth of penetration of PM into the lungs depends on the aerodynamic size of particles (Anderson et al., 2012; Kumar et al., 2025). Thus, PM_{10} and $PM_{2.5}$ are the most important health risk factors for respiratory and cardiovascular diseases and exhibit the highest biological activity. However, obtaining sufficient material for *in vitro* and *in vivo* toxicological studies is a difficult task.

Due to their extremely small size, PM_{10} and $PM_{2.5}$ not only are not retained by natural biological barriers when inhaled, and pass into the bloodstream, but they can also accumulate in the body, triggering various unpleasant health-related consequences (Feng et al., 2016). In 2013, WHO classified fine particulate matter, PM_{10} and $PM_{2.5}$, as carcinogens in the first group (World health statistics, 2018). According to the results of epidemiological, clinical and experimental studies, air pollution with PM, especially those containing metals, has been confirmed to be a risk factor for cancer of the trachea, bronchi, and lungs. Damage to the epithelial cell genome and epigenetic changes caused by PM_{10} and $PM_{2.5}$ play an important role in the pathogenesis of cancer.

The negative effects of respiratory particulate matter (PM) are manifested both in short-term exposure (from a few hours to a few days) and in long-term or chronic exposure (over several months to years). According to WHO estimates (World health statistics, 2018), an increase in PM_{10} concentration by 10 μg/m³ leads to an increase in daily mortality by 0.2-0.6%. Each increase in $PM_{2.5}$ concentration by 1 μg/ m³ is associated with a 6-13% increase in cardiopulmonary mortality risk. Daily studies in 29 European cities have shown that, with an increase in daily concentrations of PM_{10} or black smoke of 10 g/m³, there is an increase in the daily number of deaths across all ages of 0.6%. This figure is even slightly higher for the elderly (Katsouyanni et al., 2001). Under conditions of long-term exposure to $PM_{2.5}$, each increase in the concentration of suspended particles by 10 μg/m³ was accompanied by a 6-13% increase in long-term cardiopulmonary mortality risk.

In the atmospheric air of Russian cities, using calculated coefficients for PM_{10} and $PM_{2.5}$, indicators of additional mortality of the population were determined in 219 cities, amounting to 67.9 thousand cases/year under the influence of PM_{10}, and 88.2 thousand cases per year taking into account the effects of $PM_{2.5}$.

Studies in Semnan (Iran) during the COVID-19 pandemic and after quarantine showed that mortality rates from chronic obstructive pulmonary disease (COPD) related to $PM_{2.5}$ were 25.18% in 2019, 22.55% in 2020, and 22.12% in 2021. During the quarantine, mortality and hospitalization rates due to cardiovascular and respiratory diseases also decreased (Aga et al., 2003).

Data have been obtained showing that solid particles of $PM_{2.5}$, as a quality, cause a certain degree of deterioration in the structure and function of the epidermis of the skin (Liu et al., 2019).

The negative effect of $PM_{2.5}$ on the cognitive functions of the brain and the risk of early dementia are described (Tokbergenov et al., 2022). Even relatively low levels of $PM_{2.5}$ may be an important environmental factor influencing patterns of structural brain development in childhood

(Kim et al., 2015). The negative role of dust particles in the spread of infectious diseases, in particular COVID-19, has also been confirmed (Ghobakhloo et al., 2023).

According to the results of an assessment of the risk of non-traumatic mortality due to exposure to atmospheric air pollution in the city of Ust-Kamenogorsk, suspended particles of PM2.5 have unacceptable levels of relative risk (RR: 1.27-1.78) and individual risk for non-trauma ($1.5\text{-}2.1 \cdot 10^{-3}$) and cardiopulmonary mortality ($8.3 \cdot 10^{-4}$ to $1 \cdot 10^{-3}$) (Kenessary, et al., 2019).

Analysis of numerous works (Aga et al., 2003; Brook, 2008; Anderson et al., 2012; Katsouyanni et al., 2001; Valavanidis et al., 2010; Zheng et al., 2015; Rajper et al., 2018; Fatkhutdinova et al., 2021; Ning et al., 2024; Pavlík et al., 2012; Pope, 2000; Pope et al., 2006; Feng et al., 2016) allows us to draw the following conclusions:

- Chronic pulmonary obstruction progresses with chronic exposure to $PM_{2.5}$ and PM_{10}.
- Short-term acute exposure to $PM_{2.5}$ and PM_{10} exacerbates lung diseases;
- Short-term acute exposure to $PM_{2.5}$ and PM_{10} exacerbates lung disease. The toxic effect of $PM_{2.5}$ and PM_{10} is manifested in systemic oxidative stress in the lungs, inflammation, and vascular atherosclerosis;
- $PM_{2.5}$ and PM_{10} cause adverse changes in the autonomic function of the heart;
- $PM_{2.5}$ and PM_{10} cause changes in vascular tone and endothelial function;
- translocation of $PM_{2.5}$ and PM_{10} provokes prothrombotic effects;
- $PM_{2.5}$ and PM_{10} help to reduce the body's defenses and immunity.

Thus, the risk of dangerous exposure to suspended particles is primarily associated with fine aerosol particles of $PM_{2.5}$ and PM_{10}. The effects of $PM_{2.5}$ and PM_{10} air pollution are characterized by a wide range of diseases, including various allergic reactions of the respiratory system, such as bronchitis, asthma, runny nose, cough, and chronic obstructive pulmonary disease (COPD), etc. Susceptible populations, such as the elderly, children, and those with chronic illnesses.

The WHO estimates that air pollution caused by PM causes about 800 000 deaths annually, putting a huge burden on global public health. PM is in 13th place among the leading causes of death worldwide (Khan et al., 2010). Thus, PM air pollution requires constant monitoring as it has complex consequences for public health.

2.4. Sources of PM entering the atmosphere

There are 3 groups of particles that differ in the degree of negative effect on human health:

1. Coarse particles with an aerodynamic diameter of more than 10 microns, which irritate the mucous membranes of the upper respiratory tract and eyes, provoking cough, sore throat, allergic reactions, itching and redness of the eyes; these particles are not regulated;

2. Medium-dispersed particles have an aerodynamic diameter less than 10 micrometers (PM_{10}); they are regulated;

3. The most toxic fine particles have aerodynamic diameters less than 2.5 micrometers ($PM_{2.5}$), these particles are also regulated.

Fine suspended particles $PM_{2.5}$ and PM_{10} are the main indicators of atmospheric air quality. The concentrations of $PM_{2.5}$ and PM_{10} in atmospheric air in areas affected by enterprises often exceed the established hygienic standards (Kerimray, 2020). Instruments for monitoring the levels of $PM_{2.5}$ and PM_{10} in the atmosphere are being developed for health risk management purposes. In particular, the mass concentration of $PM_{2.5}$ is a key parameter for assessing air quality and the effects of its pollution on human health. The importance of monitoring atmospheric air quality for fine particles is reflected in the WHO's recommendations on air quality regarding particulate matter, ozone, nitrogen dioxide, and sulfur dioxide (World health statistics, 2018). In 1999, the EPA introduced the Air Quality Index (AQI) to effectively inform the public about the health risks caused by the concentration of pollutants in the environment. The AQI includes a new sub-index – fine particles (Particulate Matter (PM) Pollution, 2024).

PM emissions from mobile sources with diesel engines are regulated by a number of European vehicle emission directives, supplemented by directives on fuel quality and regulation of emissions from off-road mobile vehicles, railway locomotives and ships on inland waterways (Fatkhutdinova et al., 2021).

Currently, the quality of urban air is one of the most significant environmental issues. In most large cities around the world, air pollution is reaching critical levels. The air quality in more than 20 of the largest cities in the world is several times worse than the WHO standards.

According to Kazinform International News Agency (Nigmatullina, 2025), over the past five years there have been consistently high levels of atmospheric air pollution recorded in Karaganda, Almaty, Aktobe, Temirtau, Ust-Kamenogorsk, and Astana, due to emissions from industrial enterprises, motor transport, and the improper operation of outdated sewage treatment plants. In Astana, the air is burdened with suspended particles $PM_{2.5}$ and PM_{10}, carbon monoxide and nitrogen dioxide. In Karaganda, Temirtau and Ust-Kamenogorsk, sulfur dioxide, ammonia, hydrogen sulfide, phenol and other harmful compounds are added to them. The list of cities with "very high" pollution levels includes Almaty, Atyrau, Karaganda, Temirtau, Talgar and Satpayev. Astana, Ust-Kamenogorsk, Turkestan, Zhitikara, Kulsary were included in the category of "high level of pollution". And among the settlements with a "high level of pollution" were Aktau, Aktobe, Semey, Petropavlovsk, Shymkent and 16 other cities.

The criteria for atmospheric air quality, in relation to the maximum permissible levels of $PM_{2.5}$ and PM_{10}, in the EU, USA, Russia, China, and Kazakhstan, are somewhat different (table 2).

Table 2. Regulatory standards $PM_{2.5}$ and PM_{10} in air

Indicator, mcg/m^3	**WHO (Particulate Matter (PM) Pollution, 2024)**	**USA (Particulate Matter (PM) Pollution, 2024)**	**EU (Kerimray, 2020)**	**China (Nhung et al., 2017)**	**Russia (Zagorodnov et al., 2018)**	**Kazakhstan (Kenessary et al., 2019, Tursumbayeva et al., 2022)**
MPC $_{PM2.5ms}$	–	–	–	–	160	150
MPC $_{PM2.5ad}$	25	35	25	35	35	35
MPC $_{PM2.5aa}$	10	12	12	15	25	–
MPC $_{PM10ms}$	–	–	–	–	300	500
MPC $_{PM10ad}$	50	150	50	50	60	150
MPC $_{PM10aa}$	20	–	20	40	35	–

[1]MPC $_{PM2.5ms}$ and MPC $_{PM10ms}$ – the maximum single permissible concentrations of PM_{10} and $PM_{2.5}$ particles in the air (20-minute averaging);
[2]MPC $_{PM2.5ad}$ and MPC $_{PM10ad}$ – the average daily permissible concentrations of PM_{10} and $PM_{2.5}$ particles in the air (24-hour averaging);
[3]MPC $_{PM2.5aa}$ and MPC $_{PM10aa}$ –the average annual permissible concentrations of PM_{10} and $PM_{2.5}$ particles in the air (annual averaging);
[4] "–" - n/a

The regulatory standards of the European Union, USA and China do not apply to assessing the maximum single concentration of $PM_{2.5}$ and PM_{10} within a 20-minute period. Instead, concentrations of suspended particulates are measured on an hourly basis. Thus, risks of acute exposure to $PM_{2.5}$ and PM_{10} to public health are assessed based on the degree of air pollution relative to average daily maximum allowable concentrations (MPC), and chronic exposure is assessed relative to the annual average MPC.

In the countries of the European Union, the maximum permissible suspended particle content of PM_{10} was first established in Directive 1999/30/EU in 1999 (Particulate Matter (PM) Pollution, 2024), and in 2008, MPC (maximum permissible concentration) for PM10 (residual mass) and MPC for $PM_{2.5}$ (particulate matter with a diameter less than 2.5 microns) were clarified in Directive 2008/50/EU on the quality of atmospheric air and clean air in Europe (Kerimray, 2020). In the USA, average daily and annual standard values for the PM_{10} content were introduced in 1987 at 150 and 50 micrograms per cubic meter, respectively (Pope et al., 2000). In 2006, current standards were revised. The average annual maximum permissible concentration for PM_{10} was abolished. However, average daily and average annual maximum concentrations for $PM_{2.5}$ were introduced. They are equal to 35 and 15 μg/m³, respectively (Nevmerzhitsky, 2016).

In accordance with WHO recommendations for the safe functioning of humans, the average daily level of $PM_{2.5}$ in surface atmospheric air should not exceed 25 μg/m³, while the recommended average annual level is no more than 10 μg/m³ (World health statistics, 2018). Standards vary markedly from country to country. In the USA, the standard for PM2.5 in the atmosphere is 35 micrograms per cubic meter (Bennett et al., 2019) and in EU countries - 25 μg/m³ (Putaud et al., 2010). In Russia, the maximum annual permissible concentration of PM_{10} is 35 and $PM_{2,5}$ - 20 μg/m³; the daily average concentration is 60 and 40 μg/m³, respectively. The maximum single concentrations for PM10 and $PM_{2.5}$ are 300 and 240 μg/m³, respectively (Zagorodnov et al., 2019). In Kazakhstan, the maximum single-use MPC values are applied, while the WHO applies average daily and annual limits for particles of PM_{10}, $PM_{2.5}$, and NO_2 to assess air quality. For example, the one-time maximum permissible concentration of $PM_{2.5}$ used in Kazakhstan is 15 times higher than the average WHO annual standard **(**Kenessary et al., 2019; Tursumbayeva et al., 2022**)**.

3. Conclusion

Currently, PM is present in the surface atmospheric air almost everywhere and continuously. It has a different chemical, morphological, and dispersed composition, as well as different sources of intake and accumulation densities. Analysis of data on PM content in atmospheric air in various cities around the world has revealed a connection between PM and the public health. The risks associated with exposure to PM include growth, exacerbation of disease, and mortality from continuous exposure. All this indicates the critical importance of monitoring small suspended particles (PM) and controlling air pollution levels, particularly in large industrial cities. Regulatory values for safe levels of particulate matter exposure (PM) vary in Kazakhstan, Russia, the EU, China, and the United States.

The instruments for state control of $PM_{2.5}$ and PM_{10} in the atmosphere in Kazakhstan are not sufficiently used for health risk management purposes. Therefore, it is essential to improve the effectiveness of environmental policies, especially in major industrial cities in Kazakhstan, in order to decrease the level of pollution caused by $PM_{2.5}$ particles and PM_{10} particles in surface air.

4. Supplementary Materials: no supplementary material

5. Author Contributions

Conceptualisation – Zh.B., N.M., Ye.P.; data curation – Ye.P., Zh.B., S.S., N.M.; formal analysis – S.S., N.M., L.K., Ye.P.; methodology – Ye.Sh., L.K., S.S.; administration – Zh.B., N.M.; visualisation – Ye.P.; writing-original draft preparation – Ye.P., Zh.B., N.M., L.K.; writing-review and editing – N.M., Zh.B., Ye.P.

6. Author Information

Baigazinov, Zhanat – PhD, chairman of the board, JSC Park of Nuclear Technologies, Kurchatov st., 18/1, Kurchatov, Kazakhstan, 180010; e-baygazinov@pnt.kz, https://orcid.org/0000-0002-0348-8473

Mukhamediyarov, Nurlan – director of Research and Development Department, JSC Park of Nuclear Technologies, Kurchatov st., 18/1, Kurchatov, Kazakhstan, 180010, LLP Scientific Research Center EventumLab, Semey, Kazakhstan, 070000; mukhamediyarov@pnt.kz, https://orcid.org/0000-0001-5073-5978

Zhumadilov, Kassym – PhD, head of the department, L.N. Gumilyov Eurasian National University, Kazhymukan st., 13, Astana, Kazakhstan, 010000; zhumadilovk@gmail.com, https://orcid.org/0000-0002-0205-4585

Polivkina, Yelena – candidate of biological sciences, associate professor, head of the department of radioecological and biodosimetric research, branch "IRSE" NNC RK, Beibit Atom st., 2B, Kurchatov, Kazakhstan, 180010; polivkina.elena75@gmail.com, https://orcid.org/0000-0002-4411-5868

Salmenbayev, Sayan – PhD doctoral student, head of the Radiochemical Research Laboratory, branch "IRSE" NNC RK, Beibit Atom st., 2B, Kurchatov, Kazakhstan, 180010; salmenbayev@gmail.com, https://orcid.org/0000-0001-7338-682X

Kenzhina, Laura – candidate of medical sciences, associate professor, head of the Laboratory of Biodosimetric Research, branch "IRSE" NNC RK, Beibit Atom st., 2B, Kurchatov, Kazakhstan, 180010; laurakenzhina@nnc.kz, https://orcid.org/0000-0002-4553-356X

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9. References

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Қалқымалы бөлшектер ($PM_{2.5}$ және PM_{10}): заманауи түсініктер және токсикологиялық бағалау

Жанат Байгазинов, Елена Поливкина, Нурлан Мухамедияров, Касым Жумадилов, Саян Сальменбаев, Лаура Кенжина

Аңдатпа. Атмосфералық ластанудың өзекті мәселелерінің бірі - қалқымалы бөлшектер ("particulate matter" – PM). Бұл бөлшектер табиғи және антропогендік шығу тегімен сипатталады. Бұл шолуда қалқымалы бөлшектер туралы заманауи түсініктер, сондай-ақ оларды классификациялау тәсілдері мен токсикологиялық қасиеттері жинақталған. Аэродинамикалық өлшемі 2,5 және 10 мкм ($PM_{2.5}$ және PM_{10}) болатын бөлшектер экологиялық тұрғыдан ең маңызды әрі қауіпті топқа жатқызылады. Антропогендік текті $PM_{2.5-10}$ атмосфералық ауада барлық жерде және тұрақты түрде кездеседі. Жерге жақын атмосфера қабатындағы $PM_{2.5-10}$ бөлшектерінің негізгі көздері - құрылыс, тау-кен өндірісі, отын-энергетика салаларының кәсіпорындары және автокөлік құралдары. Мақалада Қазақстан, Ресей Федерациясы, Европа Одағы елдері, Қытай және АҚШ-тағы $PM_{2.5-10}$ үшін қолданыстағы экологиялық нормативтерге салыстырмалы сипаттама берілген. Европа Одағы елдерінде, Қытай мен АҚШ-та, Ресей мен Қазақстанда қолданылатын $PM_{2.5}$ үшін максималды біржолғы шекті рұқсат етілген концентрациялар (ШЕК) бекітілмеген. Сонымен қатар, Европа Одағы елдері мен АҚШ-та $PM_{2.5-10}$ үшін орташа тәуліктік және жылдық ШЕК көрсеткіштері Ресей мен Қазақстанға қарағанда әлдеқайда қатаң. Европа Одағы елдері, Қытай және АҚШ-тағы $PM_{2.5-10}$ бөлшектерінің тұрақты әсері туралы деректерді талдау негізгі қауіп топтарын анықтауға мүмкіндік берді. Бұл қауіптер жүрек-қантамыр және тыныс алу жүйесі ауруларының өсуімен, сондай-ақ осы аурулардың созылмалы түрлерінің асқынуы салдарынан халық өлім-жітімінің артуымен байланысты. $PM_{2.5-10}$ токсикологиялық әсерін бағалаудың күрделілігі олардың химиялық құрамы мен морфологиясының айтарлықтай біртекті еместігімен және тұрақсыздығымен, сондай-ақ дисперсиялық қасиеттерімен түсіндіріледі. Тәуекелдерді басқарудың және халық денсаулығының көрсеткіштерін жақсартудың негізгі құралы - $PM_{2.5-10}$ ластану деңгейін төмендету. Қазақстанда $PM_{2.5-10}$ мөлшерін мемлекеттік бақылау құралдары да атмосфералық ауаның ластануын азайтуға бағытталған, бірақ олар халық денсаулығына төнетін қауіптерді басқару міндеттерін шешуде жеткілікті деңгейде қолданылмай отыр.

Түйін сөздер: атмосфералық ауа; қатты бөлшектер; PM_{10}; $PM_{2.5}$; токсикологиялық бақылау; нормалау; денсаулыққа қауіптер.

Взвешенные частицы ($PM_{2.5}$ и PM_{10}): современные представления и токсикологическая оценка

Жанат Байгазинов, Елена Поливкина, Нурлан Мухамедияров, Касым Жумадилов, Саян Сальменбаев, Лаура Кенжина

Аннотация. Одной из современных проблем атмосферного загрязнения являются твердые частицы ("particulate matter" – PM). PM имеют как природное, так и антропогенное происхождение. В обзоре обобщены современные представления о твердых частицах (PM), а также о подходах к их классификации и токсикологических свойствах. К наиболее экологически значимым и опасным относят частицы с аэродинамическим размером 2,5 и 10 ($PM_{2,5}$ и PM_{10}). $PM_{2,5}$ и PM_{10} антропогенного происхождения присутствуют в атмосферном воздухе практически повсеместно и постоянно. Основными источниками $PM_{2,5}$ и PM_{10}в приземной атмосфере являются предприятия строительной, горнодобывающей, топливно-энергетической отраслей и автомобильный транспорт.

В статье дана сравнительная характеристика существующих экологических нормативов для $PM_{2,5}$ и PM_{10} в Казахстане, Российской Федерации, странах Евросоюза, Китае и США. В странах Евросоюза, Китае и США отсутствуют максимально разовые предельно допустимые концентрации (ПДК) для $PM_{2,5}$, применяемые в Российской Федерации и Казахстане. При этом страны Европейского Союза и США используют более строгие нормативы среднесуточной и среднегодовой ПДК $PM_{2,5-10}$, чем в Российской Федерации и Казахстане.

Анализ данных о постоянном воздействии $PM_{2,5-10}$ в странах Европейского Союза, Китая, США позволил выделить основные группы рисков, которые связаны с ростом целого ряда заболеваний сердечно-сосудистой и дыхательной систем, а также смертностью населения на фоне обострения хронической формы данных заболеваний. Сложность оценки токсикологического влияния $PM_{2,5-10}$ обусловлена значительной неоднородностью и нестабильностью их химического состава и морфологии, а также дисперсионными свойствами. Основным инструментом управления рисками и улучшения показателей здоровья населения является снижение уровней загрязнения $PM_{2,5-10}$. В Казахстане инструменты государственного контроля за содержанием $PM_{2,5-10}$ тоже нацелены на снижение уровня загрязнения атмосферного воздуха, однако они недостаточно используются для решения задач управления рисками для здоровья населения.

Ключевые слова: атмосферный воздух; взвешенные частицы; $PM_{2.5}$; PM_{10}; токсикологическая оценка; нормирование; риски для здоровья.