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THE EFFECTS OF AIR POLLUTION WITH PARTICULATE MATTER ON HUMAN HEALTH

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Abstract

This review examines the literature on particulate matter (PM), covering studies published between 2019 and 2024. Articles were selected based on their relevance to PM sources, chemical composition, atmospheric behaviour, and health impacts, prioritizing the studies in English. The review synthethizes findings on PM origin, including traffic, industrial emissions, constructing activities, and natural processes such as wildfires and volcanic eruptions. It also highlights the relationship between particle size and chemical composition, as well as the health-related effects of PM exposure, including respiratory and cardiovascular outcomes. The results underline the urgency of implementing measures to reduce PM emissions and protect public health.

Key words*: particulate matter; air; pollution; chemical composition, health impacts.*

INTRODUCTION

Air pollution represents a major issue affecting both the environment and human health. Particulate matter (PM) is one of the most damaging components found in air pollution. PM originates from a wide variety of sources, both natural and anthropogenic.

Due to its small size, PM can be inhaled easily, and its effects on human health can be severe, posing a significant risk. Numerous studies have been conducted to identify the wide range of effects caused by long-term exposure to PM, many of which have been linked to respiratory and cardiovascular diseases (Šarkan et al., 2023). Moreover, recent literature suggests potential links between PM exposure and metabolic disorders, including diabetes and obesity (Mahiyuddin et al., 2023).

Advanced wastewater treatment processes, such as the anaerobic-anoxic-aerobic (A_2O) (configuration studied by Marin et al., 2023) are pivotal in reducing environmental pollutants. By effectively removing nutrients like phosphorus from urban wastewater, these systems prevent eutrophication in aquatic ecosystems, which can lead to increased biological activity and the subsequent release of volatile compounds into the atmosphere. These compounds can act as precursors to secondary particulate matter formation, thereby contributing to air pollution. Thus, efficient wastewater treatment not only safeguards water quality but also plays an indirect role in mitigating airborne particulate matter levels, highlighting the interconnectedness of water and air pollution control strategies (Marin et al., 2023).

This review explores the origins, composition, and health impacts of PM, highlighting the significance of regulatory measures in protecting public health.

MATERIALS AND METHODS

Articles for this review were identified through searches in Scopus, Web of Science, DOAJ, and MDPI.

This review is based on the analysis of 13 articles published between 2019 and 2024, as listed in the bibliography. All included articles were directly selected for their relevance to particulate matter (PM), including its sources, chemical composition, atmospheric behaviour, and health impacts.

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Inclusion criteria were articles addressing PM origin, particle size, chemical composition, or human health effects.
Exclusion criteria were studies not related to PM or human health.
The selected articles provide the data and figures presented in this review.

RESULTS AND DISCUSSIONS

This section provides a synthesis of the findings from various studies regarding the sources and health impacts of particulate matter (PM). The results are organised into several key themes, including the primary sources of PM, the health effects associated with exposure, and the long-term consequences for both individuals and populations.

Sources of Particulate Matter (PM)

Particulate matter (PM) consists of primary and secondary particles. Primary particles, especially ultrafine particles (≤0.1µm), are directly emitted from combustion processes, including transport, industry, power generation and heating. Secondary particles (2.5-10 µm) form through atmospheric chemical reactions. PM also contains dust, biological particles, and gaseous pollutants. Ultrafine particles can originate from gaseous precursors such as sulphur dioxide and nitrogen oxides. Natural sources include volcanic eruptions, forest fires, sea spray, pollen, and fungal spores (Chauhan et al., 2024).
Figure 1 illustrates the sources of PM pollutants and their atmospheric transport. Through chemical reactions, these particles interact with water and liquid molecules, leading to their accumulation in clouds. Wind currents then facilitate their upward movement (Amnuaylojaroen & Parasin, 2024).
Particulate matter (PM) is a major contributor to atmospheric pollution. In modern settings, residential heating and vehicular emissions are the primary sources, with higher concentrations in urban areas with dense traffic. Non-exhaust emissions result from resuspension of deposited particles, road abrasion, and tire or brake wear. Overall, PM pollution is largely driven by fossil fuel combustion.
(Šarkan et al., 2023).

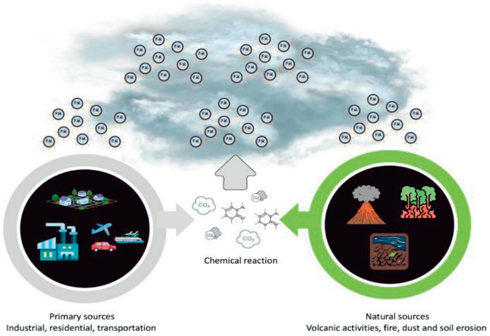

Figure 1. Emission sources of PM pollutants
(Amnuaylojaroen T., & Parasin, N., 2024)

Table 1 provides a classification of ultra fine particles according to their types, subcate-gories, and particle diameters, facilitating a better understanding of their characteristics (Chauhan et al., 2024).

Table 1. Categories of Ultra fine Particles based on their type and size (Chauhan et al., 2024)

Type		PM Diameter(µm)
Particulate contaminants	Soot	0.01-0.8
	Smog	0.01-1
	Tobacco smoke	0.01-1
	Fly ash	1-100
	Cement dust	8-100
Biological contaminants	Viruses	0.01-1
	Bacteria and Bacterial spores	0.7-10
	Fungi and moulds	2-12
	Allergens (dogs, cats, pollen, household, dust)	0.1-100
Types of dust	Atmospheric dust	0.01-1
	Settling dust	1-100
	Heavy dust	100-1000
	Different gaseous contaminants	0.0001-0.01

Figure 2 shows that ultra fine particles (UFPs) come from both natural and anthropogenic sources. On the left are natural sources of PM, and on the right are human-made sources. In the middle, UFPs are shown as resulting from both types, underlining their mixed origin (Chauhan et al., 2024).

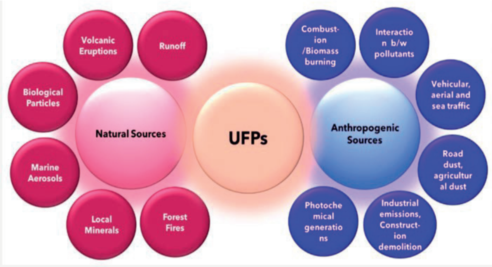

Figure 2. The main sources regarding the particulate matters (Chauhan, B.V.S. et al., 2024)

Health effects of PM exposure

Particle size is a key factor in PM toxicity. Smaller particles pose greater health risks as PM2.5 can reach the lower respiratory tract and settle in the bronchi, while particles larger than PM10 are mostly filtered by the nasal cavity. The chemical composition of PM further influences its effects. Poor air quality is a major global health threat, reducing life expectancy and surpassing even the risks of cigarette smoking (Šarkan et al., 2023).

Air pollution affects not only the respiratory system but also the cardiovascular system. PM exposure is linked to systemic inflammation, oxidative stress, endothelial dysfunction, and altered blood pressure, which can contribute to stroke and other cardiovascular conditions. The health impact of PM depends on particle size and composition. PM10 particles mostly deposit in the trachea and bronchi, while PM2.5 and ultrafine particles can reach alveoli and enter the bloodstream, spreading to other organs. PM may contain carbon monoxide, nitrates, sulphates, ozone, volatile organic compounds, heavy metals, and polycyclic aromatic hydrocarbons. Chronic PM exposure can trigger cellular stress, apoptosis, ferroptosis, pyroptosis, as well as DNA damage, epigenetic changes, and homeostatic disruption, increasing the risk of multiple disease (Lim & Kim, 2024).

The skin serves as a barrier against chemicals, pathogens, air pollutants, and UV radiation, while maintaining proper moisture levels. Keratinocytes, which make up 90% of the epidermis, respond to antigens by releasing cytokines and chemokines that regulate immune and inflammatory responses. Dysregulation of keratinocyte function can lead to excessive inflammation, contributing to skin aging and related disorders.

Figure 3 illustrates the relationship between particle size and their site of deposition in the human respiratory system. At the top, various particles such as molecules, viruses, bacteria, and pollen are shown according to their diameter, with reference to PM0.1, PM2.5, and PM10 size ranges. The bottom part of the figure illustrates how particles of various sizes accumulate in the respiratory tract. Particles between 10 and 30 µm are trapped in the oropharyngeal region; those between 2 and 10 µm reach the conducting airways; while ultrafine particles smaller than 2 µm can penetrate deep into the respiratory zone, including the alveolar ducts and sacs (Lim & Kim, 2024).

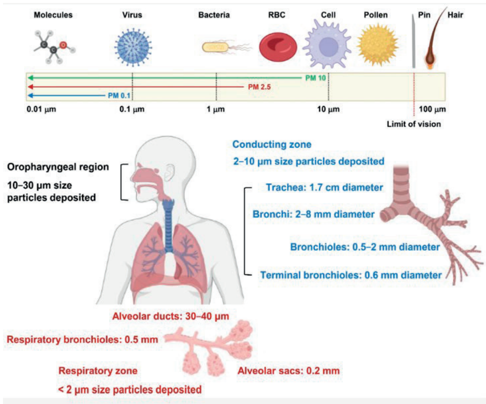

Figure 3. PM classification by aerodynamic particle size (Lim & Kim, 2024)

Constant exposure to particulate matter emissions provokes alveolar inflammation, induces disorders of the metabolic system and sets off the risk of cardiovascular diseases. In comparison, people with a history of chronic cardiovascular and respiratory diseases are much more vulnerable than others. They are significantly more susceptible to infections caused by PM exposure. Each of the two types of PM exposure, long or short term, has been associated with a high risk of cardiovascular and respiratory disease, along with the mortality rates. These associations were clearly demonstrated in earlier research, highlighting $PM_{2.5}$ as a significant contributor to non-accidental mortality (Mahiyuddin et al., 2023).

Figure 4 illustrates the human body with organs affected by particulate matter (PM) exposure, showing the brain impacted by cognitive impairment and neuroinflammation, the neck with inflammation leading to irritation, the lungs affected by respiratory issues, the liver showing signs of hepatic damage, the skin with irritation and dermatitis, the vascular system inflamed and the heart at increased risk of damage or dysfunction (Lim & Kim, 2024).

The evaluation of exposure to pollution includes two divisions of health risk: non-carcinogenic and carcinogenic risks. The heavy metals Hg, Cu, Pb, Zn, Cr, Cd, and Ni are associated with chronic non-carcinogenic health effects. Additionally, Cd, Cr, and Ni pose a carcinogenic health risk, through dust inhalation.

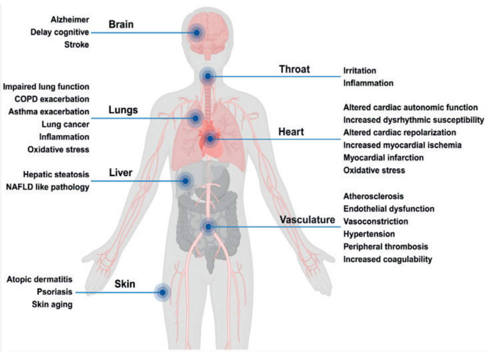

Figure 4. major affected organs by long exposure to PM (Lim & Kim, 2024)

The main routes of exposure to PM are ingestion, inhalation, and dermal absorption. The health risk assessment model is defined as follows:

$$ADD_{ing} = c*(IngR*CF*EF*ED)/(BW*AT) \quad (1)$$

$$ADD_{inh} = c*(InhR*EF*ED)/(PEF*BW*AT) \quad (2)$$

$$ADD_{derm} = c*(SA*CF*SL*ABS*EF*ED)/(BW*AT) \quad (3)$$

where:

ADD_{ing} = Daily contaminant intake via ingestion (mg/kg/day);

ADD_{inh} = Daily contaminant exposure via inhalation (mg/kg/day);

ADD_{derm} = Daily contaminant absorption through the skin (mg/kg/day);

c = contaminant concentration in the medium (e.g., soil, air, water);

IngR = Ingestion rate (amount ingested per day);

CF = Conversion factor (to ensure unit consistency);

EF = Exposure frequency (days per year of exposure);

ED = Exposure duration (total years of exposure);

BW = Body weight (kg);

AT = Averaging time (for non-carcinogens: ED × 365 days, for carcinogens: 70 years × 365 days);

InhR = Inhalation rate (volume of air inhaled per day);

PEF = Particulate emission factor (used for inhalation exposure modelling);

SA = Exposed skin surface area (cm^2);

SL = Skin adherence factor (mg/cm^2);

ABS = Dermal absorption factor (fraction of the contaminant absorbed through the skin) (Dunea, 2019).

Meteorological factors play a crucial role in disease occurrence due to PM exposure. Cold stress during winter is linked to a higher incidence of influenza and respiratory infections, which may contribute to cardiovascular complications. The accumulation of PM_{10} and its inverse correlation can be attributed to the low cloud cover and frequent fog events (Bodor et al., 2024).

Whereas the effect of air pollution on metabolic conditions has been extensively studied, its impact during pregnancy remains poorly evaluated. Pregnant women experience unique physiological changes, including increased energy intake, an accelerated basal metabolic rate, and natural insulin resistance, which may heighten their vulnerability to air pollutants. However, findings on this association remain inconclusive due to the limited number of studies focused on pregnant populations. Additional studies are needed to clearly understand the long-term exposure to PM on glucose metabolism during pregnancy and its potential effects on maternal and fetal health (Wu et al., 2024).

Long-Term Impact of PM on human health

PM pollution is higher in winter. Wind speed affects pollutant dispersion: higher speeds dilute pollutants, while lower speeds allow accumulation and prolong secondary chemical transformations (Fu et al., 2019).

Long-term exposure to PM10 (over than two years) increases non-accidental and cardiovascular mortality, particularly in individuals aged 40 and above. Older adults are more vulnerable, especially on hazy days, with higher risks of cardiovascular and respiratory diseases (Hu et al., 2023). Chronic PM2.5 exposure is linked to elevated blood pressure, thrombosis, insulin resistance, and oxidative stress in the lungs. Meta-analyses also indicate a higher risk of cardiorespiratory diseases even shortly after exposure to PM2.5 (Urbanowicz et al., 2024).

Extended observational studies over six years show that PM exposure worsens pre-existing lung conditions such as idiopathic pulmonary fibrosis (IPF) and other respiratory diseases. Fine particles can accelerate lung function deterioration and increase the risk of complications, highlighting the importance of reducing exposure for individuals with lung issues (Mariscal et al., 2024).

Certain populations are more susceptible to the harmful effects of PM. Children have developing lungs and immune systems, making them more prone to respiratory issues (Amnuaylojaroen & Parasin, 2024). Elderly individuals face higher risks of cardiovascular diseases due to prolonged exposure to PM2.5 and PM10 (Hu et al., 2023; Mahiyuddin et al., 2023). Pregnant women may experience adverse effects on fetal development from particulate exposure (Amnuaylojaroen T. & Parasin N., 2024).

To mitigate these risks, it is recommended that authorities implement air quality monitoring, stricter emission controls, and public awareness campaigns (Lim & Kim, 2024; Mariscal Aguilar et al., 2024). Sensitive groups should limit exposure to high pollution days, for example by staying indoors or using air purifiers (Mahiyuddin et al., 2023). Future research should focus on long-term health impacts in these vulnerable populations and evaluate the effectiveness of intervention strategies (Wu et al., 2024).

CONCLUSIONS

This research analyses the provenance, the composition, and the health impact of the pm on human condition after the pollution exposure.

PM derives from both natural and Anthropogenic sources, and it is classified into primary, secondary, and ultra fine particles. It results from various activities, including fossil fuel combustion, atmospheric chemical reactions, heating emissions, transportation, industrial processes, power generation, volcanic eruptions, and biological activity.

PM contains a wide range of contaminants such as dust, biological particles, gaseous pollutants, tire wear particles, carbon monoxide, nitrates, sulphates, volatile organic compounds, and heavy metals.

Health effects are mainly influenced by the size and chemical composition of PM.

Smaller particles are more hazardous upon inhalation, penetrating deeper into the body and affecting organs such as the brain, lungs, throat, heart, liver, vasculature, and skin.

Air pollution is linked not only to respiratory health issues but also to cardiovascular and cerebrovascular diseases. Moreover, prolonged exposure to PM induces systemic inflammation and DNA damage. Individuals with pre-existing chronic illnesses are particularly vulnerable to PM exposure.

Although PM exposure has also been studied in pregnant women, findings remain inconclusive due to the limited number of studies focused on this population.

Meteorological factors significantly influence the health risks associated with PM.

During winter, increased risk is observed due to cloudy days, low temperatures, and minimal wind speed, which allow pollutants to accumulate and suffer chemical transformations.

In comparison to short-term contact, long-term exposure has a deeper influence on human condition along with its outcomes linked to the age and medical history of the individual.

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