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Atmospheric Aerosols and their Effect on Human Health: A Review

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ABSTRACT

Atmospheric aerosols are one of the main pollutants which are harmful to human health and environment. Atmospheric aerosols emitted from different sources are of different sizes and depending upon the size of the aerosol particle, it deposits in different parts of the body and cause varying health problems. Fine Particulate ($PM_{2.5}$) is associated with more severe health consequences than coarse particulate (PM_{10}) which might be short-term acute symptoms like coughing, shortness of breath, wheezing, respiratory diseases, to more serious problems like asthma, Chronic Obstructive Pulmonary Disease (COPD), bronchitis, pneumonia and long-term chronic irritation and inflammation of the respiratory tract, which may eventually result in lung cancer. Inhalation of ultrafine particles (<0.1 μm) may also contribute to cardiovascular effects due to their ability to penetrate deep into the lungs and enter the bloodstream. Exposure to traffic emissions for a long time has been linked to coronary arteriosclerosis, while short-term exposure has been linked to hypertension, stroke, myocardial infarctions, and heart failure. Prolonged exposure to carcinogenic substances such as certain heavy metals and organic compounds, particularly in industrial or heavily polluted areas, may increase the risk of lung cancer and other types of cancer. However, the risk factor depends on the exposure of different groups of the population to these aerosols. Thus, highlighting the need for continued research, monitoring, and effective air pollution control strategies are required to safeguard human health and well-being.

Keywords: Asthma; Atmospheric aerosols; Cardiovascular disease; Chronic obstructive pulmonary disease (COPD); Fine particulate; Hypertension; Pneumonia; Respiratory diseases.

1. Introduction

The development in the field of science and technology has provided comforts to the entire humanity, however, man being greedy has a tempered ecosystem. The environment is deteriorating due to various kinds of pollution viz., air, water, soil, sound, etc., and hence the need for protecting the environment has emerged as an essential study. Among the different types of pollution, the most hazardous is air pollution. One of the primary pollutants that air contains is fine suspended particles known as atmospheric aerosols.

Atmospheric aerosols are solid or liquid particles suspended in the air. They include sea salt, dust, volcanic ash, soot, sulfates, nitrates, and other particles generated by human activity. Since aerosol sources are found on the earth's surface, these particles are mostly found in the lower layers of the atmosphere (1.5 km). However, certain aerosols, mainly volcanic aerosols which are ejected into the high-altitude layers are found in the stratosphere [1]. Aerosol particles come in a wide range of chemical compositions, shapes, and morphologies, and as a result, they have optical characteristics that vary greatly depending on the source, as well as production and ageing processes in the atmosphere [2], [3]. Aerosol particles range in size from a few nanometers to several tens of micrometres, except for cloud droplets and ice crystals [4]. Depending on their sizes and compositions, aerosol particles can stay in the troposphere for days to weeks [5]. Aerosols emitted from natural and anthropogenic sources scatter and absorb sunlight and terrestrial radiation. Increased atmospheric aerosol concentrations from anthropogenic activities like burning fossil fuels and burning biomass change Earth's energy balance and hence affect climate [6].

Aerosols have increased enormously over the past two decades due to population growth, rapid economic growth, and the system of energy consumption [7]. In recent years aerosols have been under significant consideration due to

their ability to affect the energy budget and their negative impact on agriculture and human health. Aerosols, from human sources, have recently been identified as an essential component of the climate system [8], [9]. More than 80% of individuals who live in metropolitan areas are exposed to air that is of lower quality than what the World Health Organisation (WHO) advises. People who live in metropolitan regions may be at an increased risk of developing chronic and acute respiratory illnesses, including asthma, as well as stroke, heart disease, lung cancer, and other health issues [10].

2. Sources of Aerosols and Classification

The sources of aerosols are either natural or anthropogenic (human-made). Natural sources of aerosols include plants, extraterrestrial or planetary dust, forests, deserts, forest fires, volcanoes, and the ocean. Burning of biomass, industrial processes, human-caused fires, transportation, and combustion of fossil fuels are anthropogenic sources [1]. After the production of aerosols in a place, they are transported away from their sources [11]. The amount of natural sources that contribute to ambient aerosols varies with time and also depends on the distance from the source areas [12]. The concentration of aerosol is relatively high close to the Earth's surface due to the presence of the sources near the surface.

Aerosols are classified into two types based on their origin- primary and secondary. Aerosols may be emitted directly into the atmosphere (primary aerosols) or created in the atmosphere from precursor gases through a chemical reaction (secondary aerosols). Primary aerosols are made up of both organic and inorganic components. The main sources of inorganic primary aerosols are sea spray, mineral dust, and volcanoes. These aerosols are relatively large (> 1 μm) and hence have a very short residence time (a few days). The primary aerosols are carried into the atmosphere by strong winds, erupting volcanoes, or smoke or fires [13].

2.1. Natural Primary Aerosols

Natural primary aerosols include sea salt particles, mineral dust, volcanic aerosols and bioaerosols. Sea-salt aerosols are generated over the ocean by many physical processes [14]. The amount of sea salt produced and its concentration depends on the wind speed and the size and phase (liquid or dry sea salt) of the sea salt aerosols that are produced after the evaporation of sea spray droplets depending on relative humidity [11]. Mineral dust aerosols are emitted due to wind friction on continental surfaces and are generated in regions where there is a strong wind and little vegetation, particularly in arid, semiarid, and desert regions. The reduced soil humidity and weaker cohesive force between the soil particles cause the emission of soil particles. Volcanoes release gases such as CO_2, SO_2, H_2S and hydrogen halides and dust particles and they enter the atmosphere [1]. The sulphur dioxide released during volcanoes reflects the incoming solar radiation, thus cooling the planet. Contrarily, carbon dioxide may contribute to global warming, but the emission of it during volcanoes is lower than that released by human activity. Living and non-living elements (fungi, bacteria, viruses, algae), dispersal units (pollen, spores), excrement of biological organisms, and plant detritus discharged from both terrestrial and marine ecosystems into the atmosphere make up bioaerosols [1], [15], [16]. Additionally, some species of the marine environment are included in this group, such as phytoplankton that emits dimethyl sulphide (DMS), a precursor to secondary natural sulphate aerosols, plants and algae that release volatile organic compounds (VOCs), and some types of trees that produce terpenes. The primary bioaerosols have an impact on atmospheric processes including cloud drop formation [17],

[18], [19] and ice nucleation [19], [20], [21], [22], [23]. The dispersal of pathogens and allergens from plants, animals, and humans has a significant impact on agriculture, public health, and the environment.

2.2. Natural Secondary Aerosols

Natural secondary aerosols are produced in the atmosphere as a result of gas-to-particle conversion processes that occur with aerosols of natural origin. Sulphates and nitrates, which are produced by the condensation of gases containing sulphur and nitrogen, are the most common natural secondary aerosols. Condensation may take place on already-existing particles, increasing their mass (but not their number), or forming new particles smaller than 0.01μm. The natural sulfate particles are produced from the dimethylsulfide (DMS) from biogenic sources (phytoplankton) and the SO_2 emitted by volcanoes. Volcanic eruptions contribute around 7% and DMS-derived aerosols roughly 19%, respectively, to the overall amount of sulphate aerosols in the atmosphere [11]. Biomass burning and forest fires are also natural sources of tropospheric sulfur dioxide [5]. The sulfate aerosols scatter the solar radiation and thereby increasing the earth's albedo and serving as cloud condensation nuclei. Nitrogen oxides, volatile acids containing nitrogen, and gaseous nitrates are the precursor gases of nitrate aerosols. Nitrogen dioxide is oxidized to nitric acid, which then reacts with ammonia or sodium chloride to form nitrate particles. Secondary organic aerosols (SOA) and carbonaceous aerosols (EC & OC) formed from gas-to-particle conversion processes from biogenic volatile organic compounds are also secondary aerosols [11].

2.3. Anthropogenic Primary Aerosols

The major primary anthropogenic aerosols that come from different sources include industrial dust, carbonaceous particles (soot) from the combustion of fossil fuels, and particles from the burning of waste and biomass. Besides carbonaceous compounds (both EC and OC), polycyclic aromatic hydrocarbons (PAH), mercury, and volatile chemical that form ground-level ozone are also emitted during the combustion of fossil fuels. The major atmospheric pollutant of biomass burning is carbonaceous aerosols which include both organic carbon (OC) and elemental carbon (EC) [24]. Environmental quality is significantly affected by the industrial dust that is released from sources such as transportation, coal or fuel combustion sectors, cement production facilities, metallurgy, and waste incineration. Anthropogenic emissions have significantly increased during the past 50 years in areas of the world where industrialisation has progressed without any pollution control measures, particularly in Asia. This growth in industrialization is expected to lead to a significant rise in industrial dust [5], [10]. The concentration of organic aerosols in the atmosphere is close to that of industrial sulfate aerosols, and these particles influence both the environment and human health [24]. The open burning significantly increases aerosols emissions into the atmosphere and have great impact on the environment and health [25].

2.4. Anthropogenic Secondary Aerosols

Secondary anthropogenic aerosols are formed through the gas-to-particle conversion of primary particles from anthropogenic sources in the atmosphere. Hydrocarbons and compounds containing sulfur and nitrogen are the main chemical species involved in the formation of secondary aerosols. The oxidation of sulfur dioxide and nitrogen dioxide gives secondary sulfate and nitrate aerosols in the atmosphere [26]. Secondary organic aerosols (SOA) are mainly formed by the atmospheric oxidation of volatile organic compounds such as trimethyl benzenes, xylenes, toluene, and alkanes emitted primarily from anthropogenic sources (gasoline) [27].

3. Chemical Components of Atmospheric Aerosols

The chemical components of the aerosols present in the atmosphere are incredibly numerous, with variable concentrations. The type of aerosol present in the atmosphere depends on its source, its formation process, and the photochemical processes. The constituents of atmospheric aerosols include water-soluble and insoluble inorganic aerosols such as anions – nitrates (NO_3^-), sulfates (SO_4^{2-}), chlorine (Cl^-), and halides and cations –ammonium (NH_4^+), sodium ions of alkali and alkaline earth elements. It also, contains trace metals (Cu, Fe, Al, Cr, Mn, Ni, Cd, Co, Li, Zn, Pb), crustal elements (Si, Al, Fe, Ca, Na, Mg, K) [11], [19], [28] and the carbonaceous aerosols, which consists of different forms of carbon like elemental carbon (EC), black carbon (BC) and organic carbon (OC)which are released from the incomplete combustion of fossil and biomass-based fuels [29], [30]. Several aerosols are non-volatile and remain in the atmosphere in the aerosol phase until they are gradually removed from the atmosphere [31]. The mass concentration of total carbon with particle size ranging from 15 to 600 nm varies from 45% to 90% depending on the source of emissions. These carbonaceous aerosols constitute the largest portion of the atmospheric aerosols and since they do not well mixed in the atmosphere, remain suspended in the air and contribute to cloud formation until it settles down or is washed out by rain [30].

4. Health Effects of Atmospheric Aerosols

Atmospheric aerosols emanating from a variety of sources are a major component of National ambient air pollution (United States Environmental Protection Agency 2002). Aerosols emitted from different sources are of different sizes: Fossil fuel combustion releases particles in the range of 100-300 nm size, whereas the dust particles are of size above 1μm [32]. Based on the size, aerosol particles are classified as coarse, fine, and ultrafine particles. Coarse particles (PM_{10}) generally accumulate in the upper respiratory tract and have an aerodynamic diameter of less than 10μm. Both fine particles ($PM_{2.5}$) of aerodynamic diameter less than 2.5μm and ultrafine particles ($PM_{0.1}$) of aerodynamic diameter less than 100 nm are deposited mostly in the lower respiratory tract, where the exchange of gases takes place [33]. Fine particulate ($PM_{2.5}$) is associated with more severe health consequences than coarse particulate (PM_{10}) [34]. Depending upon the size of the aerosol particles, it deposits in different parts of the body and cause varying health problems [32]. The studies reported that the transmission of the COVID-19 illness may be significantly impacted by PM in various size fractions (PM_1, $PM_{2.5}$, and PM_{10}) as well as gaseous air pollutants (ozone,O_3, nitrogen dioxide, NO_2, sulphur dioxide, SO_2, and carbon monoxide). Studies on epidemiology have linked respiratory and cardiovascular illness and higher death rates to outdoor acute and chronic exposure to high levels of air pollution in big cities because of their enhanced oxidative toxicity [35].

4.1. Respiratory Problems

The area of the respiratory system that is impacted by particulate matter depends on the particle size. PM_{10} affects the upper respiratory tract, whereas ultrafine particles (0.1 mm in diameter) impact the lung alveoli. Atmospheric aerosols can worsen asthma, decrease lung function, irritate the airways, cause coughing fits and other breathing difficulties, as well as cause premature death in people with lung or heart illness [36]. Atmospheric aerosols have a variety of negative health effects, including both short-term acute symptoms like coughing, shortness of breath, wheezing, respiratory diseases, to more serious problems like asthma, Chronic obstructive pulmonary disease

(COPD), bronchitis, pneumonia and high hospitalization rates and long-term chronic irritation and inflammation of the respiratory tract, which may eventually result in cancer [37], [38]. There is a strong relationship between hospital admissions for chronic respiratory disorders and $PM_{2.5}$ and PM_{10} levels [39]. Polycyclic Aromatic Hydrocarbons (PAHs) such as benzopyrene, acenaphthylene, anthracene, and fluoranthene present in coal and sediments of tar, are generated through incomplete combustion of organic matter such as motor exhaust, incineration, and forest fires. These PAHs are toxic, mutagenic, and carcinogenic and hence significantly increase the risk of developing lung cancer [38], [40]. Exposure to heavy metals such as arsenic, lead and nickel is responsible for asthma, emphysema and even lung cancer [41], [42]. Exposure to bioaerosols cause respiratory diseases such as asthma, hay fever, organic dust toxic syndrome, hypersensitivity pneumonitis, and chronic bronchitis [43]. The industrial emission and coal mining activities produce atmospheric pollutants including certain heavy metals and they pose health risk especially chromium (Cr). The concentration of these metals increases during sandstorm days. Long-term exposure to Cr can lead to lung cancer and respiratory tract inflammation because it can precipitate certain blood proteins [44].

Endotoxin which is an organic dust and a significant component of bioaerosols is released into the atmosphere from agricultural operations, in animal housing and in food processing industries, has great impact on human health. Long-term exposure to bacterial endotoxin raises the danger to respiratory health, with endotoxic shock being the most frequent complication. Endotoxin intensifies respiratory symptoms including coughing and wheezing with shortness of breath as concentration rises [45].

After the COVID-19 pandemic epidemic, several investigations revealed the presence of SARS-CoV-2 in Particulate Matter (PM) due to the potential role that PM might play as a carrier of pathogenic bacteria and viruses. High concentrations of these PM might have a detrimental impact on the respiratory system [46].

4.2. Cardiovascular Problems

Exposure to aerosols, especially $PM_{2.5}$ and smaller ultrafine particles (UFPs), has been linked to cardiovascular issues. exposure to $PM_{2.5}$ and other aerosol components is associated with an increased risk of cardiovascular diseases, including heart attacks, strokes, and high blood pressure [47], [39]. Inhalation of ultrafine particles (<0.1 μm) may also contribute to cardiovascular effects due to their ability to penetrate deep into the lungs and enter the bloodstream [48]. The cardiovascular system is known to be negatively affected by prolonged exposure. Long-term exposure to pollutants changes the blood cells and may impair heart functioning. Exposure to traffic emissions for a long time has been linked to coronary arteriosclerosis [49], while short-term exposure has been linked to hypertension, stroke, myocardial infarctions, and heart failure. According to reports, prolonged exposure to nitrogen oxide (NO_2) can cause ventricular hypertrophy in humans [50], [51]. The presence of preexisting coronary heart disease, and heart failure may also elevate short-term cardiovascular mortality risk [52].

4.3. Cancer Risk

Some components of atmospheric aerosols, such as certain heavy metals and organic compounds, have been classified as carcinogens. Prolonged exposure to these substances, particularly in industrial or heavily polluted areas, may increase the risk of lung cancer and other types of cancer [53]. Dioxins, heavy metals, and other contaminants are harmful because they bioaccumulate and obstruct cellular processes [54], [55]. The particles

released from diesel engines have mutagenic and carcinogenic properties and hence exposure to these particles leads to lung cancer [56].

4.4. Other Effects

Particulate matter entering the body can harm the immune system and reduce the immune capacity of the body, increasing the risk of a variety of diseases [57]. The fine particles enter the respiratory system by inhalation and respiratory, and cardiovascular problems, as well as reproductive and central nervous system disorders, and cancer. In addition, air pollutants that are harmful to human health include nitrogen oxide, sulphur dioxide, volatile organic compounds (VOCs), dioxins, and polycyclic aromatic hydrocarbons (PAHs). Depending on the exposure, heavy metals like lead can either cause acute poisoning or chronic intoxication when absorbed into the human body [38].

The impact of these aerosols on human health can be decreased by reducing emission by human activities and improving the air quality. The study reported that during COVID-19 pandemic, the quality of air was improved due to the imposition of lockdown. the COVID-19 shutdown decreased human activity, which led to lower air pollution concentrations being measured over all of India [58].

5. Conclusion

Atmospheric aerosols have a significant negative health effect, including both short-term acute symptoms like coughing, shortness of breath, wheezing, respiratory diseases, to more serious problems like asthma, Chronic obstructive pulmonary disease (COPD), bronchitis, pneumonia and high hospitalization rates and long-term chronic irritation and inflammation of the respiratory tract, which may eventually result in cancer. It is important to note that the health effects of atmospheric aerosols can vary depending on factors such as the composition of the aerosols, the duration and intensity of exposure, and individual susceptibility. Vulnerable populations, such as the elderly, children, and individuals with pre-existing respiratory or cardiovascular conditions, are particularly at risk. Implementing air quality legislation, reducing emissions from industrial and transportation sources, promoting the use of renewable energy sources, and increasing public awareness about the value of both indoor and outdoor air quality are all ways to lessen these consequences.

Overall, the health effects of atmospheric aerosols are a significant public health concern. There is need for continuous research work both at urban and rural areas to monitor the atmospheric aerosols to better understand their health effects. Efforts to reduce air pollution and promote cleaner energy sources can help minimize exposure to harmful aerosols and protect public health.

Declarations

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Competing Interests Statement

The authors have declared no competing interests.

Consent for Publication

The authors declare that they consented to the publication of this study.

Authors' Contribution

All the authors took part in literature review, research, and manuscript writing equally.

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