SPANDIDOS PUBLICATIONS
EXPERIMENTAL AND THERAPEUTIC MEDICINE 28: 460, 2024

Saharan dust and respiratory health: Understanding the link between airborne particulate matter and chronic lung diseases (Review)

VASILIKI EPAMEINONDAS GEORGAKOPOULOU[1], CHRYSOULA TASKOU[2], ATHINA DIAMANTI[2], DESPOINA BEKA[3], PETROS PAPALEXIS[4,5], NIKOLAOS TRAKAS[6] and DEMETRIOS A. SPANDIDOS[7]

[1]Department of Pathophysiology, Laiko General Hospital, National and Kapodistrian University of Athens, 11527 Athens, Greece; [2]Department of Midwifery, Faculty of Health and Caring Sciences, University of West Attica, 12243 Athens, Greece; [3]Department of Ear, Nose and Throat, Laiko General Hospital, 11527 Athens, Greece; [4]Unit of Endocrinology, First Department of Propedeutic and Internal Medicine, Laiko General Hospital, National and Kapodistrian University of Athens, 11527 Athens, Greece; [5]Department of Biomedical Sciences, University of West Attica, 12243 Athens, Greece; [6]Department of Biochemistry, Sismanogleio Hospital, 15126 Athens, Greece; [7]Laboratory of Clinical Virology, School of Medicine, University of Crete, 71003 Heraklion, Greece

Received June 19, 2024; Accepted October 11, 2024

DOI: 10.3892/etm.2024.12750

Abstract. Saharan dust storms, which originate from the Sahara desert, have a significant impact on global health, especially on respiratory conditions of populations exposed to fine particulate matter that travels across continents. Dust events, characterized by the transport of mineral dust such as quartz and feldspar, lead to the suspension of particulate matter in the atmosphere, capable of traversing long distances and affecting air quality adversely. Emerging research links these dust episodes with increased incidence and exacerbation of lung diseases, including asthma and chronic obstructive pulmonary disease, especially during peak dust emission seasons from November to March. The present review aims to synthesize existing scientific evidence concerning the respiratory health impacts of Saharan dust, examining the environmental dynamics of dust transmission, the physical and chemical properties of dust particles, and their biological effects on human health. Further, it assesses epidemiological studies and discusses public health strategies for mitigating adverse health outcomes. Given the complexity of interactions between atmospheric dust particles and respiratory health, this review also highlights critical research gaps that need attention to better understand and manage the health risks associated with Saharan dust.

Correspondence to: Dr Vasiliki Epameinondas Georgakopoulou, Department of Pathophysiology, Laiko General Hospital, National and Kapodistrian University of Athens, 17 Agiou Thoma Street, 11527 Athens, Greece
E-mail: vaso_georgakopoulou@hotmail.com

Key words: Saharan dust, respiratory health, particulate matter, Sahara desert, public health strategies

Contents

1. Introduction

Saharan dust storms, also known as Saharan dust events, are natural phenomena characterized by the transport of vast quantities of mineral dust from the Sahara Desert across the African continent and beyond. These dust events occur predominantly during the dry season, typically from November to March, when intense atmospheric pressure systems over North Africa drive the movement of dust-laden air masses towards the Atlantic Ocean and surrounding regions. In West Africa, the Harmattan winds are a specific example of winds that can deliver Saharan dust, but other wind patterns contribute to dust transport across wider areas (1,2).

The Sahara desert, the largest hot desert in the world, serves as the primary source of Saharan dust emissions. With its extensive arid and semi-arid landscapes, the Sahara experiences frequent dust uplift due to strong surface winds, convective processes, and occasional thunderstorms. The resulting dust plumes can travel thousands of kilometers, crossing international borders and affecting diverse ecosystems, from the Caribbean to the Amazon rainforest and even reaching as far as Europe and North America (3,4).

The global impact of Saharan dust storms is profound, influencing various environmental, atmospheric and socio-economic processes. Dust particles suspended in the atmosphere play a crucial role in modulating Earth's radiative balance, affecting regional and global climate patterns through the scattering and absorption of solar radiation. Additionally, Saharan dust deposition contributes essential nutrients, such as iron and phosphorus, to marine and terrestrial ecosystems, influencing ecosystem dynamics and productivity (5,6).

Furthermore, Saharan dust can have significant implications for air quality and human health, particularly in regions downwind of dust source areas. Dust storms can elevate levels of particulate matter (PM) in the atmosphere, including coarse and fine particles capable of penetrating deep into the respiratory system. This can exacerbate respiratory conditions, trigger allergic reactions, and contribute to cardiovascular morbidity, posing risks to vulnerable populations, such as children, the elderly, and individuals with pre-existing respiratory diseases (7,8).

In recent years, there has been increasing recognition of the association between exposure to Saharan dust particles and the incidence and exacerbation of lung diseases. While research on this topic is still evolving, emerging evidence suggests that inhalation of Saharan dust may contribute to respiratory symptoms, exacerbate pre-existing lung conditions, and increase the risk of developing respiratory illnesses (9,10).

The composition and characteristics of Saharan dust particles, including their size distribution, mineralogical composition, and surface chemistry, play a critical role in determining their biological effects on the respiratory system. Fine dust particles, with diameters <2.5 micrometers (PM2.5), are of particular concern due to their ability to penetrate deep into the lungs and potentially induce inflammation, oxidative stress and tissue damage (11).

The associations between Saharan dust events and adverse respiratory health outcomes in affected populations are well documented. These include an increase in hospital admissions for respiratory conditions, such as asthma exacerbations, chronic obstructive pulmonary disease (COPD) exacerbations and respiratory tract infections, during periods of elevated dust concentrations. Additionally, epidemiological investigations have identified correlations between dust exposure levels and respiratory symptoms, such as coughing, wheezing and shortness of breath, particularly among individuals with underlying respiratory conditions (12,13).

The present review focuses on the critical interactions between Saharan dust particles and respiratory health, highlighting how the unique physical and chemical properties of the dust exacerbate conditions such as asthma and COPD, particularly in vulnerable populations.

2. Composition and characteristics of Saharan dust

Origins and pathways of Saharan dust transport. The Sahara desert, spanning over 9 million square kilometers, serves as the primary source of Saharan dust emissions (14). Dust uplift events occur throughout the year but peak during the dry season, from late fall to early spring, when intense surface heating leads to convective instability and strong winds across the desert region. These winds, often associated with the Saharan heat low and the Azores high pressure systems, drive the movement of dust-laden air masses towards the Atlantic Ocean and surrounding continents (15).

Several pathways facilitate the long-range transport of Saharan dust across the globe. The most prominent is the Saharan Air Layer (SAL), a well-defined layer of warm, dry and dusty air that extends from the Sahara across the tropical North Atlantic. The SAL acts as a conduit for dust particles, carrying them thousands of kilometers westward towards the Caribbean, South America and North America. Additionally, atmospheric circulation patterns, such as the African easterly jet and the African easterly waves, play crucial roles in transporting dust plumes across Africa, Europe and the Mediterranean basin (16-18).

The interplay between synoptic weather systems, regional topography and land-atmosphere interactions influences the spatial and temporal variability of dust emissions and transport. Dust storms can originate from various source regions within the Sahara, including the Bodele Depression in Chad, the Bodélé Escarpment in Niger, and the Libyan desert, each characterized by unique geomorphological features and dust emission mechanisms. Moreover, episodic weather phenomena, such as convective thunderstorms and haboobs (dust storms associated with cold fronts), can locally enhance dust production and mobilization, leading to intense dust storms with significant impacts on air quality and visibility (19,20).

Chemical composition of Saharan dust particles. Saharan dust particles are predominantly mineralogical in nature, composed primarily of silicates, carbonates, oxides and sulfates derived from the weathering and erosion of geological formations in the Sahara desert. Quartz, feldspar and clay minerals are among the most abundant components of Saharan dust, reflecting the diverse lithological composition of the source regions (21).

In addition to mineral dust, Saharan dust particles may also contain organic matter, trace elements and anthropogenic pollutants, resulting from surface interactions, atmospheric processing, and mixing with pollution plumes during transport (22).

The chemical composition of Saharan dust particles varies spatially and temporally, reflecting differences in source rock types, weathering processes, and atmospheric processing during transport. Elemental analysis of dust samples has revealed enrichment in elements such as silicon, aluminum, iron, calcium, magnesium and potassium, which are characteristic of silicate minerals abundant in the Sahara region (23). Additionally, trace elements, including heavy metals such as lead, cadmium and zinc, may be present in Saharan dust particles, originating from both natural sources and anthropogenic activities within the source region (24).

Furthermore, chemical reactions occurring on the surface of dust particles during atmospheric transport can alter their composition and properties, affecting their reactivity, hygroscopicity and potential health impacts. For example, iron-rich dust particles can act as carriers of bioavailable iron, which may stimulate biological productivity in marine and terrestrial ecosystems upon deposition (25). Additionally, the interaction of dust particles with atmospheric gases, such as sulfur dioxide and nitrogen oxides, can lead to the formation of secondary aerosols and affect regional air quality and climate (26).

Physical properties and atmospheric behavior. Saharan dust particles exhibit a wide range of physical properties, including size, shape, density and aerodynamic characteristics, which influence their transport, deposition and atmospheric behavior (27).

Dust particles generated by aeolian processes in the Sahara desert range in size from submicron (<1 μm) to coarse (>10 μm) particles, with the majority falling within the fine (<2.5 μm) and coarse (2.5-10 μm) fractions (28). Fine dust particles, known as PM2.5, are of particular concern due to their potential to penetrate deep into the respiratory system and impact human health (29).

The shape and morphology of Saharan dust particles vary depending on their mineralogical composition and the processes involved in their formation and transport. Dust particles may exhibit angular, irregular, or spheroidal shapes, reflecting differences in the degree of weathering, abrasion and transport history. Coarse particles tend to be more angular and irregular, while fine particles may undergo rounding and surface smoothing during long-range transport, resulting in more spherical shapes (30).

The density of Saharan dust particles also varies depending on their mineral composition and porosity, with typical values ranging from 2.5 to 3.5 g/cm^3 for silicate minerals such as quartz and feldspar. Coarse dust particles tend to have higher densities than fine particles due to their larger grain sizes and higher packing densities. Additionally, the aerodynamic properties of dust particles, such as settling velocity and terminal velocity, play a crucial role in determining their transport and deposition patterns in the atmosphere and the environment (31,32).

Atmospheric behavior of Saharan dust particles is influenced by a complex interplay of meteorological factors, including wind speed and direction, atmospheric stability, turbulence, and vertical mixing processes. Dust particles injected into the atmosphere by surface winds can be transported over long distances by prevailing winds aloft, reaching altitudes of several kilometers and forming extensive dust plumes. The vertical distribution of dust in the atmosphere is controlled by atmospheric stability and vertical mixing processes, with higher concentrations typically observed near the surface during dust events and loftier layers aloft during transport (33,34).

3. Health effects of Saharan dust exposure on the respiratory system

Inhalation of PM and its effects on lung health. PM is a complex mixture of solid and liquid particles suspended in the air, varying in size, composition and origin. Inhalation of PM, particularly fine and ultrafine particles, can have detrimental effects on respiratory health, ranging from acute irritation to chronic lung diseases and cardiovascular morbidity. Saharan dust events contribute to elevated levels of PM in the atmosphere, exposing populations to increased health risks, especially in regions downwind of dust source areas. Fine dust particles, PM2.5, pose the greatest health concern due to their ability to penetrate deep into the respiratory system and reach the alveolar region of the lungs. Upon inhalation, PM2.5 particles can induce inflammation, oxidative stress and cellular damage in lung tissues, leading to a range of adverse respiratory effects. Additionally, ultrafine particles (<0.1 micrometers) can translocate across the respiratory epithelium into systemic circulation, potentially exacerbating cardiovascular diseases and systemic inflammation (35,36).

The biological mechanisms underlying the respiratory effects of PM inhalation are multifaceted and involve inflammatory responses, oxidative stress and disruption of cellular signaling pathways. PM particles can activate immune cells, such as macrophages and neutrophils, leading to the release of pro-inflammatory mediators, cytokines and reactive oxygen species (ROS) (37,38).

Chronic exposure to PM has been associated with airway inflammation, epithelial damage, mucous hypersecretion and impaired lung function, contributing to the development and progression of respiratory diseases, including asthma, chronic bronchitis and COPD (39,40).

Association between Saharan dust events and respiratory symptoms. Epidemiological studies have provided evidence of associations between Saharan dust events and adverse respiratory health outcomes in affected populations. During dust storm episodes, increases in ambient PM concentrations have been correlated with elevated rates of respiratory symptoms, exacerbations of pre-existing lung conditions, and hospital admissions for respiratory illnesses. These associations are particularly pronounced in vulnerable individuals, such as children, the elderly and individuals with underlying respiratory diseases (41,42).

A study conducted in the Caribbean region found that increases in PM10 concentrations during Saharan dust episodes were associated with higher rates of emergency room visits for asthma exacerbations and acute respiratory infections in children (43). Similarly, investigations in West Africa have reported elevated levels of respiratory symptoms, such as coughing, wheezing and shortness of breath, among residents exposed to high dust concentrations during Harmattan periods (44). Furthermore, longitudinal studies have identified temporal trends linking dust exposure to changes in respiratory health indicators, including decreased lung function, increased airway reactivity, and higher medication use among asthma and COPD patients during dust storm seasons (45).

Impact on vulnerable populations, such as children, elderly and pregnant women. Vulnerable populations, such as children, the elderly and individuals with pre-existing respiratory conditions, are particularly susceptible to the adverse health effects of Saharan dust exposure. Children, whose respiratory systems are still developing, may experience exacerbated symptoms of asthma and respiratory infections during dust storm episodes due to increased airway inflammation and susceptibility to respiratory irritants (46).

Elderly individuals, especially those with underlying cardiovascular diseases or compromised lung function, are at higher risk of experiencing respiratory symptoms and exacerbations of chronic conditions during dust events. Reduced lung elasticity and impaired mucociliary clearance in the elderly can exacerbate the deposition and retention of dust particles in the airways, leading to respiratory distress and functional decline (47). Furthermore, individuals with pre-existing respiratory diseases, such as asthma, COPD and allergic rhinitis, may experience worsened symptoms and decreased disease control during Saharan dust episodes. The pro-inflammatory and irritant properties of dust particles can trigger airway inflammation, bronchoconstriction and exacerbations of respiratory conditions, necessitating increased medication use and healthcare utilization among affected individuals (48,49).

Vodonos *et al* (50) identified a positive correlation between dust storms and hospitalization rates for COPD exacerbations, showing a 16% increase in Southern Israel. This effect was more pronounced with age and higher in women. In a laboratory study involving young healthy adults, researchers found that women had 11-23% greater deposition of inhaled particles in the central airways compared with men (51). This sex disparity was most evident with coarser particles (>5 μm). Women may experience greater susceptibility to air pollution, including dust, due to physiological factors such as smaller lung volume and airway size, leading to more particulate deposition in the lungs. The elevated concentration of PM in the central airways leads to greater irritation and inflammation, potentially triggering acute COPD exacerbations (52). During pregnancy, a woman's respiratory system undergoes significant changes, including a 20% increase in oxygen consumption to accommodate the increased oxygen demands of her and the growing fetus (53). As a result of these changes, pregnant women are particularly vulnerable to the effects of air pollution because of the increased number of pollutants inhaled.

Air pollution can trigger common respiratory diseases such as asthma and allergic rhinitis. The major adverse maternal outcome associated with air pollution is maternal hypertensive disorders such as pre-eclampsia (54). A meta-analysis of 33 cohort studies revealed that exposure to PM10 increased the relative risk (55). Furthermore, an increasing number of research suggests that maternal exposure to PM may also impact the fetus. Pollutants can cross the placenta, entering the fetal circulation during gestation (56).

Maternal exposure to Saharan dust appears to influence the fetal lung development and respiratory system after birth. A study evaluated that exposure to PM2.5 was associated with tachypnea of the newborn, asphyxia and respiratory distress syndrome (57). Different studies have looked at the effects on fetal growth. A systematic review of 52 studies and a meta-analysis of 54 studies found that maternal exposure to PM2.5, PM10 and other air pollutants was generally positively associated with low birth weight (58).

4. Mechanisms underlying the pathogenicity of Saharan dust

Inflammatory responses triggered by dust particle exposure. Inhalation of Saharan dust particles can trigger inflammatory responses in the respiratory system, leading to acute and chronic respiratory conditions. Upon deposition in the airways, dust particles activate innate immune cells, such as macrophages and neutrophils, through pattern recognition receptors and toll-like receptors (59,60). Recognition of microbial components and danger-associated molecular patterns on the surface of dust particles induces the production of pro-inflammatory cytokines, chemokines and ROS by immune cells, initiating an inflammatory cascade. It has been demonstrated that exposure to Saharan dust induces significant expression of pro-inflammatory cytokines such as GM-CSF and G-CSF, which play crucial roles in the exacerbation of respiratory conditions (61). Pro-inflammatory cytokines, such as tumor necrosis factor-alpha (TNF-α), interleukin-1 beta (IL-1β), and interleukin-6 (IL-6), recruit additional immune cells to the site of inflammation and activate downstream signaling pathways, amplifying the inflammatory response (62,63). Chemokines, such as interleukin-8 (IL-8), promote the migration of neutrophils and other immune cells to the airways, further exacerbating inflammation and tissue damage. Additionally, ROS generated by activated immune cells contribute to oxidative stress, lipid peroxidation and DNA damage, exacerbating inflammatory responses and tissue injury (64,65).

Chronic exposure to Saharan dust particles can lead to sustained inflammation and airway remodeling, characterized by epithelial hyperplasia, mucus hypersecretion, fibrosis and smooth muscle hypertrophy, contributing to the pathogenesis of respiratory diseases such as asthma, chronic bronchitis and COPD (66,67). Furthermore, interactions between inflammatory mediators and neural pathways can exacerbate airway hyperresponsiveness and bronchoconstriction, leading to respiratory symptoms and functional impairment (68).

Moreover, it has been highlighted that airborne particles such as PM2.5, cigarette smoke and diesel exhaust can induce endothelial dysfunction, promoting inflammation and increasing the risk of chronic respiratory diseases (69).

Activation of immune pathways and oxidative stress. In addition to inflammatory responses, exposure to Saharan dust particles can activate immune pathways and induce oxidative stress in the respiratory system. Dust particles contain a variety of biologically active components, including microbial antigens, endotoxins, metals and organic pollutants, which can stimulate immune cells and promote inflammatory and immune responses. Upon inhalation, Saharan dust particles interact with the respiratory epithelium, triggering an inflammatory response that can exacerbate pre-existing respiratory conditions. The interaction of fine PM (PM2.5) with immune cells, such as macrophages, further amplifies oxidative stress, leading to airway hyperresponsiveness and long-term damage (70,71).

Endotoxins, derived from the outer membrane of gram-negative bacteria, are abundant in Saharan dust and can activate toll-like receptor 4 (TLR4) signaling pathways, leading to the production of pro-inflammatory cytokines, such as interleukin-1 beta (IL-1β) and interleukin-6 (IL-6), by immune cells (72,73). Additionally, microbial components and allergens present in dust particles can trigger allergic immune responses, leading to the production of immunoglobulin E antibodies and the activation of mast cells and eosinophils, contributing to allergic asthma and allergic rhinitis (74).

Oxidative stress, resulting from an imbalance between the production of ROS and antioxidant defenses, is a common feature of Saharan dust-induced inflammation and respiratory injury. Dust particles can contain transition metals, such as iron, manganese and copper, which catalyze the generation of ROS through Fenton and Haber-Weiss reactions, leading to lipid peroxidation, protein oxidation and DNA damage in lung tissues (75,76). Additionally, ROS can activate redox-sensitive transcription factors, such as nuclear factor kappa B (NF-κB) and activator protein 1 (AP-1), leading to the upregulation of pro-inflammatory genes and the perpetuation of inflammatory responses (77,78). Moreover, inhalation of Saharan dust has been demonstrated to induce oxidative stress and activate the NLRP3 inflammasome, leading to significant release of pro-inflammatory cytokines, thereby exacerbating lung inflammation (79).

Contribution to the development and exacerbation of lung diseases. The inflammatory and oxidative effects of Saharan dust exposure contribute to the development and exacerbation of various respiratory diseases, including asthma, chronic bronchitis, COPD and allergic rhinitis. Acute exposure to high levels of Saharan dust particles can trigger asthma exacerbations and respiratory symptoms in susceptible individuals, leading to increased medication use, emergency department visits, and hospital admissions (80,81).

Chronic exposure to Saharan dust particles can exacerbate pre-existing respiratory conditions and impair lung function over time, particularly in vulnerable populations, such as children, the elderly, and individuals with underlying lung diseases. The persistent inflammatory responses induced by dust exposure can lead to airway remodeling, fibrosis and bronchial hyperresponsiveness, contributing to the progression of chronic respiratory diseases and the development of irreversible airflow obstruction (82,83).

Furthermore, Saharan dust exposure may interact with other environmental pollutants, such as vehicular emissions, industrial pollutants and biomass burning aerosols, to exacerbate respiratory health effects and increase the risk of adverse outcomes. Synergistic interactions between dust particles and other pollutants can amplify inflammatory responses, oxidative stress and airway injury, leading to more severe respiratory symptoms and poorer health outcomes (84). The various respiratory health effects associated with the inhalation of Saharan dust particles are illustrated in Fig. 1.

5. Geographic variability and environmental factors influencing health outcomes

The health effects of Saharan dust exposure exhibit geographic variability, with differences observed in the magnitude and frequency of dust events, as well as in the susceptibility of populations to respiratory health effects. Environmental factors, including meteorological conditions, air pollution levels, land use patterns and socio-economic factors, play crucial roles in modulating the health impacts of dust storms and influencing health outcomes in affected regions.

Regions located downwind of major dust source areas, such as the Sahel region of West Africa and the Caribbean islands, experience higher levels of dust exposure and are more susceptible to respiratory health effects during dust events (85). The frequency and intensity of dust storms in these regions are influenced by seasonal weather patterns, such as the West African monsoon and the North Atlantic Oscillation, which affect dust emission, transport and deposition processes (86).

Additionally, environmental factors such as air pollution levels and background PM concentrations can interact with Saharan dust particles to exacerbate respiratory health effects and increase the risk of adverse outcomes. Coarse and fine PM from local sources, such as vehicular emissions, industrial pollution and biomass burning, can mix with Saharan dust plumes during transport, leading to elevated levels of airborne pollutants and exacerbating air quality problems in dust-affected regions (87).

Furthermore, socio-economic factors, including housing conditions, access to healthcare and socio-demographic characteristics, can influence the vulnerability of populations to dust-related health risks. Socio-economically disadvantaged communities, such as low-income neighborhoods and rural settlements, may face greater challenges in accessing healthcare services, implementing preventive measures and mitigating the impacts of dust storms on respiratory health (88).

6. Mitigation strategies and public health implications

Strategies for reducing exposure to Saharan dust particles. Mitigating exposure to Saharan dust particles requires a multi-faceted approach involving individual actions, community measures and environmental management strategies. While it may not be possible to completely eliminate exposure to dust particles, several strategies can help reduce the risk of respiratory health effects associated with dust storms.

To mitigate the infiltration of outdoor air laden with dust particles into indoor environments, it is advised to keep windows and doors closed during dust events. Additionally, employing air purifiers equipped with high-efficiency particulate air filters can effectively remove dust particles from indoor air sources (14). During episodes of poor outdoor air quality resulting from dust storms, individuals are encouraged to utilize face masks or respirators. Optimal choices for filtration include N95 respirators, designed to effectively filter fine PM, thereby reducing the inhalation of dust particles (89). Enhancing indoor air quality can be achieved through the installation of air filtration systems in various settings such as homes, schools and workplaces. Employing high-efficiency HVAC filters aids in capturing airborne dust particles and preventing their re-circulation within indoor environments (90).

Mitigating dust impacts within urban settings necessitates the integration of urban design elements such as green spaces, street trees and vegetated buffers. Furthermore, incorporating dust control measures into construction projects and infrastructure development endeavors aids in minimizing dust emissions (91). Employing dust suppressants, such as water sprays, chemical stabilizers and soil binders, offers an effective approach to reduce dust emissions from unpaved roads, construction sites and open land areas. Consistent application of these techniques, including regular surface wetting, aids in controlling dust and preventing its resuspension by wind. Promoting awareness regarding the health risks associated with exposure to Saharan dust and advocating preventive measures are essential components of public health initiatives. Dissemination of educational materials, issuance of health advisories, and implementation of outreach programs serve to inform communities about dust-related health hazards and encourage the adoption of protective measures (2).

Public health interventions to mitigate respiratory health risks. In addition to individual and community-level strategies, public health interventions play a critical role in mitigating respiratory health risks associated with Saharan dust exposure.

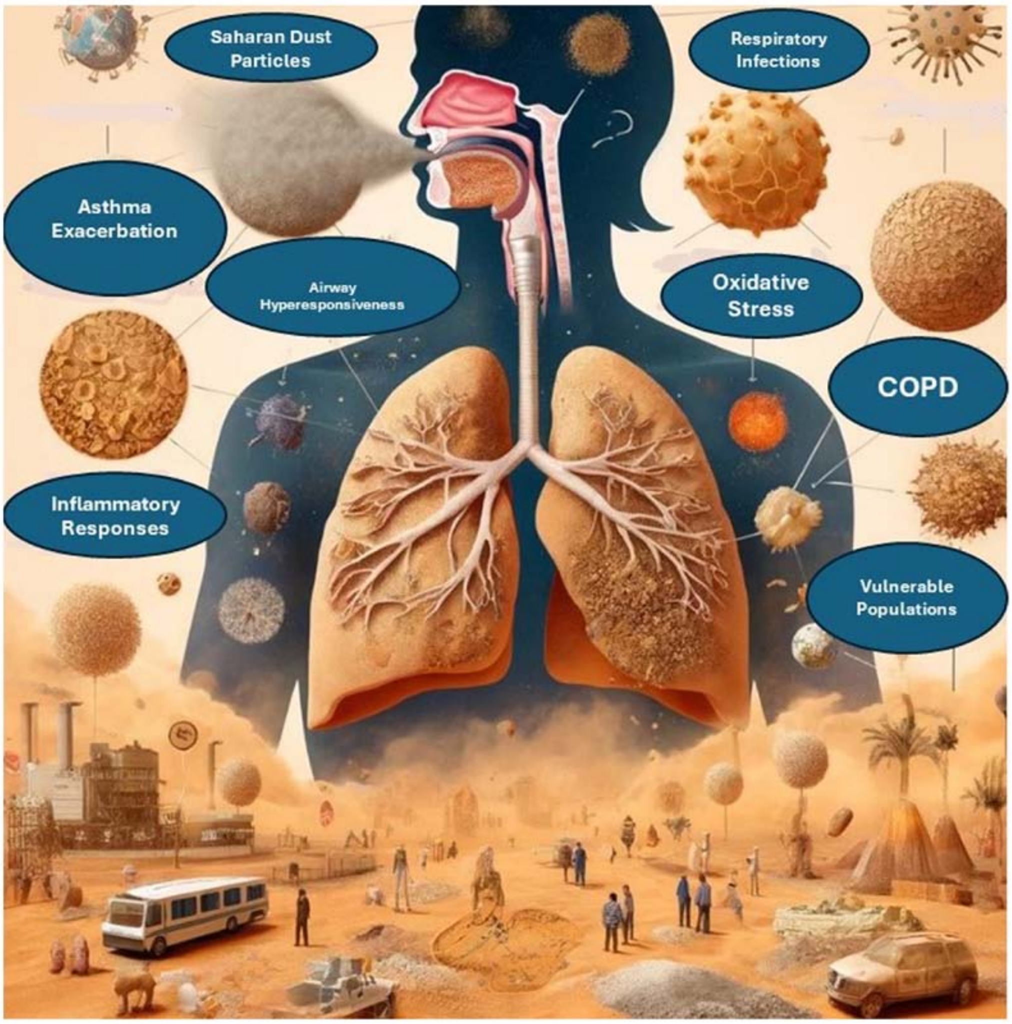

Figure 1. Impact of Saharan dust on respiratory health. This figure illustrates various health conditions associated with exposure to Saharan dust particles, including asthma exacerbation, airway hyperresponsiveness, inflammatory responses, respiratory infections, oxidative stress and COPD. Vulnerable populations, such as individuals with pre-existing respiratory conditions and children, are particularly at risk. Dust particles can cause significant respiratory issues through pathways such as oxidative stress and airway inflammation. COPD, chronic obstructive pulmonary disease.

These interventions aim to enhance surveillance, monitoring and response efforts to protect vulnerable populations and reduce the burden of dust-related respiratory diseases.

Establishing and maintaining air quality monitoring networks is crucial for tracking dust concentrations and pollutant levels during dust events. Real-time monitoring data should be utilized to issue air quality alerts, advisories, and warnings to the public and healthcare providers (92).

The development and implementation of health surveillance systems are essential to monitor respiratory symptoms, hospital admissions and mortality rates during dust events. Collecting and analyzing epidemiological data enables the assessment of the impact of dust exposure on respiratory health outcomes and identification of at-risk populations (45).

Developing emergency response plans and protocols is imperative to address respiratory health emergencies associated with Saharan dust storms. Coordination with healthcare facilities, emergency responders, and public health agencies ensures timely access to medical care and support services for affected individuals (81).

Providing training and education for healthcare providers on the recognition, diagnosis, and management of respiratory conditions related to Saharan dust exposure is essential. Promoting evidence-based clinical practices and treatment guidelines facilitates the management of acute exacerbations and complications of dust-related respiratory diseases (82).

Engaging community stakeholders, advocacy groups, and local organizations in dust awareness campaigns, public forums, and community-based interventions is vital. Partnerships with schools, workplaces and community centers facilitate the dissemination of health information and promotion of preventive measures (71).

Policy recommendations and future directions for research and action. Addressing the public health implications of Saharan dust exposure necessitates coordinated efforts across multiple sectors, including environmental protection, public health, urban planning, and climate resilience. Future research should focus on understanding the complex interactions between Saharan dust and urban pollutants, as well as their combined effects on respiratory health. Identifying how these interactions differ based on geography and population demographics could inform more effective public health interventions. The following policy recommendations and future research priorities can guide efforts to mitigate dust-related respiratory health risks and promote sustainable development.

Developing comprehensive air quality management strategies that address the sources, transport, and impacts of Saharan dust on respiratory health is imperative. Integrating dust monitoring and mitigation measures into existing air quality management frameworks and regulations is recommended (84).

Incorporating dust-related health risks into climate adaptation and resilience plans is essential for safeguarding public health in the face of climate change. Implementing strategies to enhance community resilience, build adaptive capacity, and reduce vulnerability to dust storms and other environmental hazards is crucial (59).

Fostering collaboration and knowledge exchange among countries affected by Saharan dust storms is essential. Promoting regional cooperation and joint initiatives to address transboundary air pollution and cross-border health impacts facilitates the sharing of best practices, research findings and capacity-building efforts (93).

Investing in research and innovation to advance understanding of the mechanisms, drivers, and health effects of Saharan dust exposure is necessary. Supporting interdisciplinary research projects, observational studies, and modeling efforts improves predictive capabilities and informs evidence-based interventions (94).

Ensuring coherence and alignment between policies related to air quality, public health, environmental management and sustainable development is critical. Integrating dust mitigation measures into national and regional policy frameworks, including climate action plans, health strategies and disaster risk reduction policies, promotes policy integration and coherence (95).

These recommendations and future directions underscore the importance of proactive measures and collaborative approaches in addressing the complex challenges posed by Saharan dust exposure and its implications for respiratory health and sustainable development.

7. Conclusions

In summary, Saharan dust storms pose significant respiratory health risks, driven by the transport of mineral dust across continents. Inhalation of PM from these events exacerbates respiratory conditions and increases the risk of developing lung diseases, particularly among vulnerable populations. Tailored mitigation strategies, including air quality management and public health interventions, are essential for addressing these risks. Collaboration, research investment and policy coherence are vital for effective mitigation and promoting sustainable development in the face of Saharan dust exposure.

Acknowledgements

Not applicable.

Funding

Not funding was received.

Availability of data and materials

Not applicable.

Authors' contributions

AD and VEG conceptualized the study. AD, CT, VEG, PP, DB, NT and DAS made substantial contributions to data interpretation and analysis, and wrote and prepared the draft of the manuscript. AD and VEG analyzed the data and provided critical revisions. All authors contributed to manuscript revision, read and approved the final version of the manuscript. Data authentication is not applicable.

Ethics approval and consent to participate

Not applicable.

Patient consent for publication

Not applicable.

Competing interests

DAS is the Editor-in-Chief for the journal, but had no personal involvement in the reviewing process, or any influence in terms of adjudicating on the final decision, for this article. The other authors confirm that they have no competing interests.

Use of artificial intelligence tools

During the preparation of this work, artificial intelligence tools were used to improve the readability and language of the manuscript or to generate images, and subsequently, the authors revised and edited the content produced by artificial intelligence tools as necessary, taking full responsibility for the ultimate content of the present manuscript.

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