

▶ INTERNATIONAL PERSPECTIVES



Climate Change, Dust Storms, Vulnerable Populations, and Health in the Middle East: A Review

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Abstract The impact of dust storms on human health has been well described in Asian and European countries. Several research studies have examined adverse health outcomes attributable to dust and dust storm events, including respiratory and cardiovascular diseases, across these and other developed countries. Despite an increasing number of dust storm events plaguing the Middle East attributable to climate change, little is presently understood about the effects of dust storms on the health of human populations residing in this region. This review sought to identify and assess what is currently understood about the health impacts of dust storms in the Middle East. A systematic review was designed and conducted using MEDLINE/PubMed and Google Scholar. Out of 534 articles identified, 16 met predetermined eligibility criteria and were included in our analysis. Our review identified a number of health consequences associated with dust events in the region of interest, existing gaps in available literature, vulnerable populations, and directions for future research.

Introduction

In recent decades, growing bodies of literature have acknowledged climate change and variability as threats to human health and safety. Existing research has focused on increasing temperatures, rising sea levels, increased frequency and intensity of extreme weather events, and air pollution, among other events associated with climate change. Less frequently studied are the impacts of dust storms on human health, despite increases in the frequency and intensity of such events (Schweitzer et al., 2018). Climate variability and drought—two key climate change factors associated with the increased occurrence and severity of dust storms—are caused by

the draining of wetlands, decreased levels of vegetation, unsustainable development, and increased land degradation (Akpinar-Elci et al., 2015; Bell et al., 2018).

While the majority of dust storms are concentrated in drylands, the threats posed by dust storms transcend regional and continental boundaries. Existing research has determined that dust particles have the capability to travel long distances. Saharan dust, for example, can travel across the Atlantic Ocean into the Americas and the Amazon, and has been recognized as the principal source of dust in the Mediterranean Sea (Schweitzer et al., 2018). Dust particles, along with air pollution, have been recognized as some of the

most significant predisposing factors to non-communicable diseases in the world (Gervandi et al., 2017).

Although dust transcends political boundaries and poses risks to the health and human safety of populations worldwide, specific regions are at increased vulnerability to suffer from the consequences associated with these climate events. The Middle East has been recognized as one of the largest dust-producing regions in the world, with different locations within this region frequently exposed to local and regional dust systems, including dust originating in the Sahara (Najafi et al., 2017; Schweitzer et al., 2018). Dust storms are most prominent in the Middle East during the summer months, an event pattern attributable to the presence of shamal winds (i.e., fierce winds from the northwest) and an increasing number of cyclones in the region (Choobari et al., 2014; Parolari et al., 2016; Schweitzer et al., 2018). The highest density of dust sources in the Middle East include the northern region of Iraq and along the Syria–Iraq border (Parolari et al., 2016).

Dust particles, particularly particulate matter <10 μm in diameter (PM_{10}) and coarse particulate matter ($\text{PM}_{2.5-10}$), have been recognized to adversely impact air quality (De Sario et al., 2013; Kabatas et al., 2014). Dust events in the Middle East are associated with a considerable amount of airborne PM_{10} . It has been estimated that approximately 85% of dust generated in the Middle East is smaller than PM_{10} in size (Schweitzer et al., 2018). Other studies have reported high concentrations of suspended particles and PM_{10} during dust storms in the Middle East, and

strong associations between high levels of PM₁₀ concentrations and Saharan dust events (Kabatas et al., 2014; Shahsavani et al., 2017). Hosseini et al. (2015) found that concentrations of PM₁₀ were considerably higher during dusty days compared with non-dusty days, highlighting the relationship between these climate events and resulting air quality in increasingly susceptible regions. The effects of dust storms are not limited solely to increased concentrations of PM₁₀. Studies have also established associations between levels of water-soluble ions, metals, and dust events. Pirsahab et al. (2014) reported increased concentrations of heavy metals (lead, cadmium, arsenic, mercury, and chromium) in dust samples collected for the study; most heavy metal levels were beyond the acceptable concentration levels established by the World Health Organization. Similarly, Öztürk and Keleş (2016) found increased concentrations of magnesium, silicon, and aluminum attributable to dust events.

Overall, existing literature has established strong associations between dust events and hazardous air quality, further framing the critical need to develop an improved understanding on the effects of dust storms on human health. Recent research has focused on exploring the health effects of dust storms primarily across the European region and other developed countries. Despite the increased vulnerability of the Middle East to dust storm events, the health impacts of dust storms on populations across this region have not yet been thoroughly explored. The goal of our study was to assess what is presently understood about the impact of dust storms on the health of populations in the Middle East.

Methods

A systematic review was designed to answer the research question: “In what ways do dust storms impact the health of populations in the Middle East region?” We conducted the literature search using MEDLINE/PubMed and Google Scholar. We considered articles for inclusion if they were published in English during 2008–2019.

We used keywords Middle East, dust storm, and health. After initial review, we also included keywords for each Middle East country’s name, dust storm, and health (e.g., “Iran, dust storm, health”). We defined and identified countries in the Middle East using

the U.S. Central Intelligence Agency’s World Factbook (www.cia.gov/library/publications/the-world-factbook/wfbExt/region_mde.html). The definition of “Middle East region” has changed over time with the number of countries in the region presently unsettled. Different resources have differing definitions on which countries and territories are included when using the terminology “Middle East region.” As a result of these discrepancies, we made the decision to include Egypt as a territory belonging to the Middle Eastern region.

This review included only studies that examine diseases, health outcomes, or health conditions afflicting human populations that have been strongly associated with local dust storms in the Middle Eastern countries predetermined by the study team. Literature was limited to include only full-text articles published in scientific journals. Studies on dust from volcanic activity or those originating or resulting from human activities were excluded, as these topics are outside of the scope of this review and do not align with the overall goal of our study. Those studies on dust exposure or dust levels that failed to consider or discuss the impacts of such events on human health were also excluded, as they did not provide the detail required to meet eligibility criteria. Because the present study aimed to review health outcomes among human populations associated with dust storms, we excluded any articles focused on animal populations.

All articles extracted for review were assessed by the study team to confirm compliance with eligibility criteria and appropriateness. The extraction process consisted of two stages: 1) title and abstract review and 2) full-text review for adherence to eligibility criteria guidelines.

Results

A total of 534 articles matched the initial screening criteria based on their title or abstract. Of these articles, 31 were deemed eligible for full-text review, which resulted in the exclusion of 15 articles. The main reasons for excluding these 15 studies were a) lack of clarity surrounding the human health impacts of exposure to dusts and b) the use of animal subjects. A total of 16 articles adequately met the criteria outlined for our review (Table 1, Figure 1).

While study locations varied, the majority of the articles eligible for inclusion focused on populations within Iran ($n = 11$). Two studies focused on populations within Kuwait, one within both Kuwait and Iraq, one within Turkey, and one within Israel. Studies varied in both purpose and methodology, with some focused on threats to human health resulting from dust composition and others focused more heavily on measurable health impacts attributable to dust storm events.

Infectious Agents and Diseases

Two studies examined dust composition as a hazard to human health. Leski et al. (2011) studied airborne particles within dust samples collected in Iraq and Kuwait; their study detected a number of pathogens in dust samples collected that had the potential to adversely impact human health through inhalation. *Coxiella burnetii*, recognized to cause the respiratory illness Q fever, was found in a number of samples collected over the time their study took place.

Nourmoradi et al. (2015) conducted a similar study in Iran investigating the relationship between dusty days and airborne particles containing potentially hazardous microorganisms. Similar to the findings of Leski et al. (2011), Nourmoradi et al. detected the presence of several potentially hazardous airborne bacteria and fungi in air samples assessed. The pathogens detected included *Bacillus* spp. and *Mycosporium* spp., which have the potential to adversely impact respiratory health through the onset or development of conditions such as asthma, pneumonia, or respiratory infections. This study was able to establish a relationship between increased dust (dusty day occurrence) and increased airborne microorganism concentrations.

A study by Alavi et al. (2014) investigating the relationship between dust and pulmonary tuberculosis (TB) found that while dust did not increase the overall prevalence of TB in the population, it did have the potential to impact TB relapse and treatment outcomes, as well as increased the risk for the incidence of multidrug-resistant TB (MDR-TB). Study authors observed an increase in the prevalence of TB cases among women, children, and urban residents over the study period, which suggests increased vulnerability for disease occurrence among individuals in any of these groups. Interestingly, the authors

TABLE 1

Summary of Articles Included for Analysis

Author (Year)	Country	Study Purpose	Main Findings	Health Impact
Alavi et al. (2014)	Iran	To investigate the relationship between dust and pulmonary tuberculosis (TB)	Soil dust had no obvious effect on TB prevalence. Study authors found, however, that soil dust had the potential to influence TB relapse, TB emergence, and adversely impact treatment outcomes.	TB relapse and emergence
Al-Hemoud et al. (2018)	Kuwait	To assess the environmental burden of dust storms on morbidity and mortality	Dust particulates were strongly correlated with acute lower and upper respiratory disorders and infections, as well as asthma. Additionally, there were strong associations between dust storms and morbidity rates of asthma.	Respiratory diseases and morbidity
Amarloei et al. (2015)	Iran	To evaluate respiratory tract function of a population exposed to dust storms	There was a statistically significant negative relationship between the time a resident had inhabited the region of interest and respiratory capacity, which suggests possible reductions in pulmonary function as a result of long-term exposures to dust storms.	Reductions in pulmonary function
Ebrahimi et al. (2014)	Iran	To evaluate the possible effects of dust storms on cardiovascular and respiratory disease incidence	There was a statistically significant correlation between PM ₁₀ levels and the number of cardiovascular patients admitted during dust storm events. There was a correlation between concentration of PM ₁₀ and hospitalizations for respiratory disease on dust event days; however, the correlation was not statistically significant.	Increased hospital admissions for cardiovascular diseases
Geravandi et al. (2017)	Iran	To determine the number of hospital admissions for respiratory diseases attributed to PM ₁₀ during normal and dust storm days	There was a positive correlation between dust events and hospital admissions for respiratory diseases. Cases of respiratory disease during dust events increased over the study period. Hospital admissions were higher during dust event days compared with normal days.	Increased hospital admissions for respiratory diseases
Gheybi et al. (2014)	Iran	To determine the effects of dust air pollution on the immune system, specifically on immune system lymphocytes	Individuals exposed to dust air pollution secrete higher levels of cytokines recognized to be involved in the development of allergic responses. Ambient exposure to dust air pollution affects the immune system.	Allergic inflammation
Goudarzi et al. (2017)	Iran	To assess the impact of dust events in the Middle East on hospital admissions for COPD, cardiovascular and respiratory diseases, and respiratory mortality	Pollution peaks associated with dust storms adversely affect health. Increases in PM ₁₀ were associated with increases in respiratory mortality as well as hospital admissions for respiratory and cardiovascular diseases.	Increased respiratory mortality as well as hospital admissions for cardiovascular and respiratory diseases
Khaniabadi et al. (2017)	Iran	To estimate the effects of dust storms on hospital admissions related to cardiovascular and respiratory diseases	Excess cardiovascular and respiratory morbidity were recorded on normal, dusty, and dust event days in the Middle East. Hospital admissions for both cardiovascular and respiratory diseases were highest on dusty days.	Increased hospital admissions for respiratory and cardiovascular diseases

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found an increase in secondary cases of TB attributable to close contacts in dusty conditions likely resulting from diminished treatment impacts. Prognostic indicators used to measure the success of TB control programs decreased over the study period, increasing treatment failure rates from 2.5% to 5.0%.

Increased Hospitalization Risk

Several studies showed increased risk for respiratory and cardiovascular hospitalizations attributable to dusty days and dust storm events. A study in Kuwait assessing the

potential relationship between dust storms, asthma, and respiratory-related hospital admissions found a statistically significant relationship between dust events and the outcomes of interest (Thalib & Al-Taiar, 2012). Dust storm events were associated with increases of 4–8% in respiratory admissions. The study also found that children with asthma were particularly vulnerable to the impacts of dust storm events. Geravandi et al. (2017) found similar results in Iran and established a positive correlation between dust events and hospital admissions for respi-

ratory diseases. Analyses in that study found that hospital admissions for respiratory diseases and conditions were higher on dusty days when compared with non-dusty days.

Three studies eligible for inclusion in our review examined the effects of dust and dust storm events on cardiovascular hospital admissions. Goudarzi et al. (2017) found that rates of respiratory mortality and hospital admissions for respiratory and cardiovascular diseases increased with dust events that elevated PM₁₀ levels. Similar studies found statistically significant relationships between

TABLE 1 continued

Summary of Articles Included for Analysis

Author (Year)	Country	Study Purpose	Main Findings	Health Impact
Leski et al. (2011)	Iraq and Kuwait	To investigate the potential for airborne dust to contain human pathogens	Analysis of collected samples resulted in the detection of a number of pathogens that might cause disease in humans. The two most prevalent bacteria found with the potential to act as human pathogens were <i>Mycobacterium</i> and <i>Brucella</i> . <i>Coxiella burnetii</i> , known to cause Q fever, was also detected in a number of samples collected.	Potential for infectious diseases contracted through inhalation
Neisi et al. (2017)	Iran	To compare children's fractional exhaled nitric oxide values and lung function as parameters of adverse health effects of air pollution in dusty and normal days	Short-term exposure to high particulate matter concentrations adversely affected lung function among children. Significant decreases in lung function were observed on dusty days when compared with normal days.	Decreased lung function
Nourmoradi et al. (2015)	Iran	To investigate the relationship between airborne particles containing microorganisms on normal versus dusty days	<i>Bacillus</i> spp., <i>Cladosporium</i> spp., and <i>Mycosporium</i> spp. were the most common microorganisms detected during both normal and dusty days. Airborne bacteria and fungi microorganism concentrations increased on dusty compared with normal days.	Increases in the prevalence of potential disease-causing organisms
Saeb et al. (2013)	Iran	To assess the effect of dust and sand on coagulation state	Dust has the potential to reduce prothrombin time and increase platelet levels, fibrinogen degradation, and factor VII levels. These changes in coagulant factors have the potential to increase the risk for cardiovascular diseases.	Irregularities in coagulation factors and risk for cardiovascular diseases
Soleimani et al. (2019)	Iran	To assess the effects of particulate matter on heart disease	There was a significant relationship between particulate matter and hospital referrals for cardiovascular patients. PM ₁₀ increased the risk of cardiovascular events.	Cardiovascular disease
Soy et al. (2016)	Turkey	To investigate the effects of dust storms on the quality of life of patients with allergic rhinitis, with or without asthma	Dust storms adversely impact the quality of life and lung capacity of patients with asthma and allergic rhinitis. Patients with both asthma and allergic rhinitis reported poorer quality of life after dust storms when compared with those without asthma.	Reduced quality of life and increased respiratory symptom presence
Thalib and Al-Taiar (2012)	Kuwait	To assess the potential relationship between dust events and asthma and respiratory-related hospital admissions	Authors found a statistically significant association between the occurrence of dust storm events and asthma and respiratory-related hospital admissions. Children with asthma were particularly vulnerable to dust storms events.	Increased hospital admissions for respiratory conditions
Vodanos et al. (2015)	Israel	To determine if high levels of particulate matter from dust storms pose risks to cardiovascular health and identify individual characteristics that modify potential health effects	Exposure to nonanthropogenic particulate matter was associated with an increased risk of acute coronary syndrome. Age, gender, and ethnicity were found to be significant risk factors for adverse cardiovascular outcomes.	Increased hospital admissions for acute coronary syndrome; cardiovascular diseases and outcomes

elevated PM₁₀ levels attributable to dust storm events and cardiovascular and respiratory hospital admissions (Ebrahimi et al., 2014; Khaniabadi et al., 2017; Soleimani et al., 2019). Vodanos et al. (2015) explored the relationship between increased PM resulting from dust storms and hospital admissions for acute coronary syndrome in Israel. The authors found that women were at increased risk for adverse health outcomes, which was similar to findings by Alavi et al. (2014). Women, particularly those over the age of 65, and individuals who identified as Bedouin

Arabs were at increased risk for hospitalization for acute coronary syndrome following dust storms (Vodanos et al., 2015).

Elevated Risk for Adverse Health Outcomes

Several studies were able to establish relationships between adverse health outcomes and dust storms. Two such studies identified through our analysis worked to establish links between lung function and dust storm events. Amarloe et al. (2015) identified a statistically significant negative relation-

ship between respiratory function tests and duration of inhabitation in an area heavily impacted by dust events. These findings suggest pulmonary function can be adversely impacted by long-term exposure to dust storms. Neisi et al. (2017) found decreases in the values on pulmonary function tests among school-aged children on dusty days. Study authors concluded that short-term exposure to high PM concentrations can adversely impact lung function. In addition to reductions in lung capacity, other studies established strong associations between dust

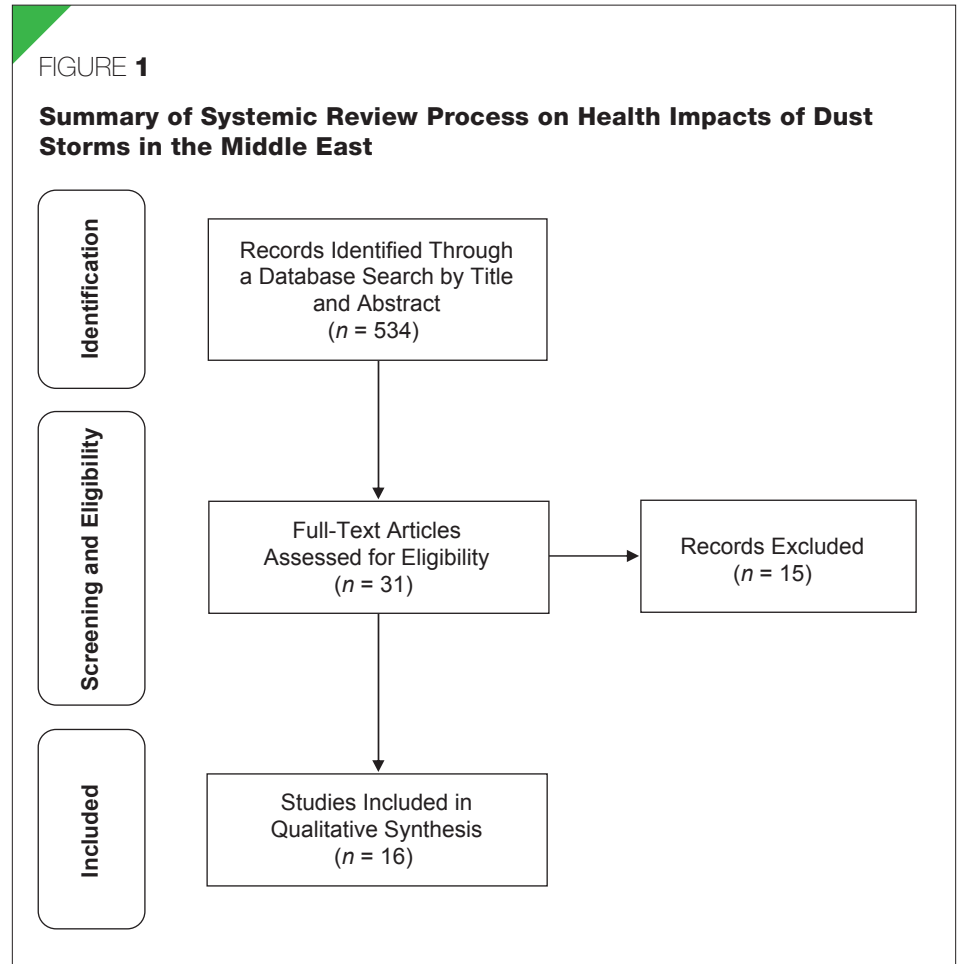
storm events, asthma-associated morbidity, and acute upper and lower respiratory tract infections (Al-Hemoud et al., 2018).

A study conducted by Gheybi et al. (2014) established a relationship between dust events and allergies. The authors concluded that frequent exposures to dust air pollution increased allergic inflammation and suggested a potential relationship between ambient air pollution and the rising prevalence of allergic diseases among a population at increased risk for exposure to dust. Having recognized the relationship between air pollutants and allergic rhinitis, Soy et al. (2016) sought to investigate the effects of dust storms on the quality of life of individuals with allergic rhinitis both with and without asthma. The authors found that dust storms were associated with impaired quality of life and reduced lung capacity, especially among individuals with asthma.

The final study we included focused on the effects of dust on coagulation and found associations between exposures to dust storm events and changes in coagulation factors including prothrombin time, platelet levels, fibrin degradation products, and factor VII levels (Saeb et al., 2013). These changes in coagulation factors impact coagulation time, and as such have the potential to threaten the cardiovascular health of individuals.

Discussion and Conclusion

Current research has suggested that environmental changes, including climate variability, changes in global and regional climate patterns, desertification, and human factors such as agricultural practices and resource management are responsible for the increasing frequency and intensity of dust events (Krasnov et al., 2014; Middleton, 2019; Najafi et al., 2017; Parolari et al., 2016). Human interference and climate change likely will continue to effect dust sources and contribute to the expansion of susceptible arid lands that are a source of dust emissions, increasing the likelihood for dust events in the future (Lababpour, 2020). Increasing dust storm events pose threats to the health of populations across the globe; however, populations across the Middle East where dust sources are abundant are at increased likelihood to suffer negative health consequences. Although the overall occurrence and intensity of dust storm events in the Middle East have increased significantly in recent decades and



relationships have been established between dust and adverse health outcomes, epidemiological research exploring the relationships between dust events and health among populations in the Middle East continues to be limited (Goudie, 2014; Najafi et al., 2017).

Dust storms are one of the most prominent natural sources of air pollution in the Middle East and have been recognized to affect population health through a number of physical and physiological hazards. Our review found that dust storm events and dust were associated with increased risk for hospital admissions for both respiratory and cardiovascular events, reductions in lung function and capacity, irregularities in blood coagulation, and increases in allergic inflammation, as well as increased risk for diseases associated with exposures to airborne human pathogens. While the mechanisms by which dust directly impacts the development or onset of adverse health outcomes have yet to be thoroughly studied, research has been able to establish

significant relationships between dust storm events and unfavorable health consequences among populations in the Middle East.

Researchers focused on the effects of dust among populations in European and Asian countries as well as the U.S. have identified subgroups at increased vulnerability for adverse health consequences associated with dust. Children, pregnant individuals, older adults, those reporting lower levels of income, and those with preexisting cardiovascular and respiratory diseases have been identified to be the most susceptible to the effects of dust storm events in these nations (Chien et al., 2014; De Sario et al., 2013; Goudie, 2014; Li et al., 2018; Yu et al., 2013). Studies conducted in the Middle East identified similar patterns of vulnerability in children, women, and individuals with asthma who are at increased risk for hospitalization and adverse health outcomes associated with exposures to dust storm events. Additionally, studies conducted in the Middle East also presented evidence that dust

has the potential to exacerbate serious conditions and diseases, such as TB (Alavi et al., 2014). Dust adversely affected symptoms, prognosis, and recovery time for those with TB, suggesting increased vulnerability among TB patient subgroups. Despite the identification of vulnerable subgroups across existing literature, there has been little exploration on the effects of dust storms on these specific groups across nations in the Middle East. Given the expanding body of knowledge that suggests increasingly serious health outcomes attributable to dust storm events, the current lack of research surrounding the impacts of dust storms on vulnerable groups presents a critical gap in literature. For example, a study conducted in West Africa established strong associations between neonatal mortality and exposure to dust events, while a study in Kuwait identified women and older adults to be at increased risk for mortality attributable to dust storm exposure (Achilleos et al., 2019; Karimi et al., 2020).

In addition to the vulnerability of specific subgroups to succumb to the effects and hazards associated with dust storms, refugees comprise another potentially susceptible population not currently studied. It is estimated that more than 7 million people have fled from conflict zones to neighboring countries including Jordan, Iraq, and Turkey, among others (Silbermann et al., 2016). Refugees have unique health, cultural, and social challenges. Syrian refugees, in particular, are more frequently afflicted by chronic and non-communicable diseases than other refugee populations, often requiring expensive treatment and care. They also face various social and physiological issues in adapting to host environments, along with language barriers, difficulties in accessing healthcare, and financial hardships. Existing research has suggested that nationality has the potential to impact susceptibility to dust storm events

(Achilleos et al., 2019). As such, Syrian refugees potentially represent a population at increased vulnerability for adverse health consequences attributable to dust storm events and should be considered as a population of interest for future studies.

To our knowledge, this article is the first systematic review to assess the health impacts of dust storms on populations across the Middle East. While we made every effort to be methodological and comprehensive, the findings presented in our review are not without limitations. The majority of articles we identified and included in our review focused on populations within Iran. Studies taking place in Iran were well justified and explained the increased risk of the population in the region to be adversely impacted by dust storm events, emphasizing both the relevance and necessity to further explore and expand knowledge on the impacts of dust storms on the health of populations in the Middle East. While the need for such studies in Iran was well justified, no exact explanation was provided in the literature we reviewed for the lack of publications or studies assessing health outcomes associated with dust events across other Middle Eastern nations that are susceptible to dust storm events.

The majority of articles that we included in our review utilized retrospectively collected health outcome data. While analyses conducted using such data allowed for the identification of statistically significant associations between dust storm events and health outcomes of interests, studies were ultimately unable to establish causality. The inability to establish causal relationships between dust storm events and specific health outcomes of interest is a major gap in the existing literature and should be explored in future research.

Dust storm data were also collected using retrospective methodologies. Different countries used different technologies to measure dust storm events and there are likely differ-

ences that exist in the categorization of dust storms, dusty days, and non-dusty days. We found that definitions of dust storm events and related terms were not well defined in the studies we analyzed.

Although the need for research capable of establishing causal relationships between dust storms and human health outcomes is of great importance, understanding the roles of social, economic, political, and contextual factors in population vulnerability and susceptibility is equally as important. There were notable differences in subgroup vulnerability to dust storm events that have not been explained in the existing literature. While the identification of vulnerable subgroups is a significant achievement, further work needs to be done to identify and expand on the factors facilitating adverse health outcomes among at-risk groups. Expanding what is currently understood about demographic, social, economic, and political factors, as well as the biological mechanisms underlying how dust impacts human health, is a crucial step in improving health at a population level.

Furthering the understanding of how these factors impact individual susceptibility and population vulnerability will aid in the 1) development of adequate public health interventions; 2) identification of specialists and personnel to involve in the development of health, safety, and prevention efforts; and 3) development of large-scale policies aimed at improving the health and well-being of populations across Middle Eastern countries. 🌍

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