Global Health Impacts of Dust Storms: A Systematic Review

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ABSTRACT

BACKGROUND: Dust storms and their impacts on health are becoming a major public health issue. The current study examines the health impacts of dust storms around the world to provide an overview of this issue.

METHOD: In this systematic review, 140 relevant and authoritative English articles on the impacts of dust storms on health (up to September 2019) were identified and extracted from 28,968 articles using valid keywords from various databases (PubMed, WOS, EMBASE, and Scopus) and multiple screening steps. Selected papers were then qualitatively examined and evaluated. Evaluation results were summarized using an Extraction Table.

RESULTS: The results of the study are divided into two parts: short and long-term impacts of dust storms. Short-term impacts include mortality, visitation, emergency medical dispatch, hospitalization, increased symptoms, and decreased pulmonary function. Long-term impacts include pregnancy, cognitive difficulties, and birth problems. Additionally, this study shows that dust storms have devastating impacts on health, affecting cardiovascular and respiratory health in particular.

CONCLUSION: The findings of this study show that dust storms have significant public health impacts. More attention should be paid to these natural hazards to prepare for, respond to, and mitigate these hazardous events to reduce their negative health impacts.

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KEYWORDS: Air quality, desert dust, dust storm, health, PM10

Introduction

Dust storms are natural hazards and the most common sources of natural particles, including very small materials, potential allergens, and pollutants.1-5 Depending on the nature of the source of the dust, these materials and substances may include, quartz, silicon dioxide, oxides of magnesium, calcium, iron, and aluminum6,7 and sometimes a range of organic matter, anthropogenic pollutants, and salts.8 Dust storms carry millions of tons of soil into the air each year from thousands of kilometers away. They can last a few hours or a few days1-5 and distribute a large number of small particles in the air,9,10 increasing the amount of particles above the allowable threshold for human health.11,12 During a dust storm event, the concentration of PM10 (particles with an aerodynamic diameter <10 μm) and PM2.5 (particles with an aerodynamic diameter <2.5 μm) particles are often higher than the normal thresholds recommended by the World Health Organization (PM2.5: 10 μg/m3 annual mean, 25 μg/m3 24-hour mean. PM10: 20 μg/m3 annual mean, 50 μg/m3 24-hour mean).8,13 It can also exceed 6000 μg/m3 in seriously strong dust storms.14 According to the Huffman Classification of dust PM10 range (μg/m3), in dusty air, light dust storm, dust storm, strong dust storm, and serious strong dust storm days, levels can be between 50 to 200, 200 to 500, 500 to 2000, 2000 to 5000, and >5000, respectively.15 Dust storms are occurring increasingly frequently in many desert areas and arid regions around the world,3 causing extensive damage and emergencies each year.3,16-18 Therefore, dust storms have attracted increasing attention in recent
Researchers have demonstrated how dust storms affect various aspects of human life. The particles in dust storms affect weather conditions, agricultural production, human health, and the ecosystem. Evidence suggests that mineral aerosols affect cloud formation and precipitation and can reduce the acidity of precipitation. Moreover, a high density and diversity of bacteria and plant pollens have been observed during dust storms. In addition to endangering the ecosystem, dust storms have direct and indirect impacts on public health and human health. Due to their small sizes, almost all dust storm particles, that is, airborne particles (PM) can enter the respiratory tract; larger particles are often deposited in the upper respiratory tract (nasopharyngeal region, tracheobronchial region), while smaller particles can enter deep lung tissue. The physical, biological, and chemical properties of these particles can cause disorders in the health of the body, and in addition to the respiratory tract, can damage other systems of the body, including the cerebral, cardiovascular, skin, blood, and immune systems.

Research has indicated that exposure to dust particles, which can remain in the air from hours to days, can result in other problems like conjunctivitis, meningitis, and valley fever. In rare cases, it can even lead to death. Evidence further suggests that frequent exposure to dust storms can lead to increased adverse health effects in people of almost all age groups and genders. People with a history of diabetes, hypertension, cerebrovascular, or pulmonary disease are also at higher risk. Many epidemiological studies have determined the health effects of dust storms by comparing outcomes during dust storm periods with outcomes during non-dust storm periods and by assessing the correlation between dust storms or PM10 exposure and health outcomes. Many researcher have acknowledged the existence of a significant association between dust exposure and increased morbidity or mortality, but there is no consensus in this regard to date. Perez et al. stated that increased PM during dust storms caused a significant increase in mortality rate in Barcelona. Chen et al., Kashima et al., and Delangizan also noted that increased PM10 levels during Asian dust storms increased cardiovascular mortality. Some studies have reported that Middle Eastern dust storms can affect inflammation and coagulation markers in young adults, have adverse effects on pulmonary function, and increase the number of asthma patients. Conversely, some studies have either ruled out the possibility of an increase in mortality or hospitalizations of patients due to dust storm exposure or do not consider the increase to be significant.

There are mixed results and a lack of accurate and up-to-date classified data about the health impacts of dust storms on humans around the world. Moreover, the causes of dust storm-related health problems are not yet completely understood. Given the importance of the impact of dust storms on human health as well as the increasing evidence of recurring and negative impacts of these storms, and because of the lack of systematic review studies, the current study conducted an extensive review of the current literature on the impacts of dust storms on human health.

Materials and Methods
This systematic review of scientific resources identified articles related to dust storms and related human health outcomes published up to 30 September 2019. PubMed, EMBASE, Scopus, and ISI WoS (Web of Science) databases were searched for articles published in relevant journals from the 28th to the 30th of October, 2019. All peer-reviewed articles from English language journals were discovered in the primary search stage. Citations and references of all relevant articles were examined and searched manually to ensure that all relevant articles were included. The primary search used the following Medical Subject Headings (MeSH terms) and keywords: Dust* OR Kosa OR Yellow sand OR Arabian Sand OR Dust Storms AND Mortality OR Disease* OR Morbidity OR Admission* OR Health* OR “Adverse affect” OR affect*

Executive limitations: The main limitations of the current study were the lack of access to all required databases as well as the lack of access to the full text of some articles which should be obtained by correspondence with the authors of those articles. To resolve this problem, the researchers resorted to using resources from various universities inside and outside the country.

Inclusion criteria: All studies that had the full text available, that used appropriate methods and data, and that calculated the impacts of dust storms on health (eg, odds ratio, relative risk, rate ratio, regression coefficient, percentage change, excess risk, etc. in health indicators following dust storms) were included. Those in which dust storm was a major problem and those in which health indicators were analyzed were analyzed in this study without restrictions on the publication date.

Exclusion criteria: Non-English articles, non-research letters to editors, review studies, case reports, case series, specialized articles about microorganisms, animal experiments, in vitro studies, and dust from volcanic or manmade sources like stone mines or stone and cement factories were excluded.

Data collection process: The current study followed the PRISMA guidelines (PRISMA Flow Diagram). EndNote software was used to manage the retrieved articles. After all articles were entered into the software, duplicates were identified and removed. Then, 2 researchers screened the remaining articles separately based on the inclusion and exclusion criteria by reading the titles, abstracts, and keywords. After removing unrelated papers, the full text of the remaining articles were...
found and attached, and the quality of each paper in a standard format related to the type of study was assessed separately by the 2 researchers using JBI’s critical appraisal tools. In cases of disagreement between the researchers, the third researcher helped to select the most relevant items.

**Data extraction:** The information required for this study was extracted using a checklist previously reviewed and prepared, which included all the characteristics of the selected articles, including type of article, publication year, first author’s name, location of study, study design/methodology, health effects, PM fraction, and age/gender.

**Risk of bias (quality) assessment:** For quality assessment of the included papers, the Critical Appraisal Skills Program (CASP) checklist was used. The assessment was conducted by 3 independent reviewers. Discrepancies were resolved by 2 other reviewers.

**Results**

**Search results**

Out of a total of 35712 articles searched, 140 articles met the inclusion criteria (Figure 1). The majority of them were related to ecological, case crossover, and prospective studies; other studies included descriptive, retrospective, and Panel studies and 1 research letter (Table 1).

The current results showed that most data analyses investigated the effects of dust storms on health and used the generalized additive model (GAM) with nonlinear Poisson regression method to analyze the data in ecological and case-crossover studies.

Furthermore, most studies on the impact of dust storms on health were performed within the last decade (Chart 1). Most health and dust storm studies included in this study were undertaken in Japan (n = 29; 20.71%), Taiwan (n = 25; 17.85%), Korea (n = 16; 11.42%), China (n = 10; 7.14%), Spain (n = 9; 6.42%), and Iran (n = 8; 5.71%), respectively (Figure 2).

In this review, the following adverse health effects of dust storms emerged as important:

- Non-accidental death (mortality due to respiratory, cardiovascular, or cerebrovascular disease);
- Emergency medical dispatch, hospitalization or admission, and hospital visits due to respiratory or cardiovascular diseases;

**Records identified by searching the through databases**

(n = PubMed=10603) + (n = Scopus=14314)

(n = WoS= 6460) + (n = EMBASE= 4287)

Total= 35664

**Excluded**

(N= 120)

- Non-English articles
- Animal studies
- Letters to editors
- Laboratory studies
- Simulation studies
- Commentaries

**Records screened**

(N= 353)

**Full text study evaluated for eligibility**

(N= 183)

**Study excluded**

(N= 43)

**Studies included in synthesis**

(N= 140)
| Reference | First Author and Year | Study Location | Population (Age, Gender) | PM Fraction | Study Design/Methodology | Health Outcomes | Results |
|-----------|-----------------------|----------------|--------------------------|-------------|--------------------------|----------------|---------|
| Al et al. | Al et al. (2018)      | Gaziantep, Turkey | Older than 16 years     | PM$_{10}$   | Retrospective study/GAM   | Mortality of cardiovascular diseases | Congestive cardiac failure mortality, OR 0.95 (0.81–1.11) Acute coronary syndrome mortality, OR 0.40 (0.31–0.50) |
| Al-Taiar and Thalib | Al-Taiar and Thalib (2014) | Kuwait | All ages/all gender | PM$_{10}$ | Ecological time series, GAM | All-causes, respiratory, cardiovascular mortality | Respiratory mortality, RR 0.96 (0.88–1.04) Cardiovascular mortality, RR 0.98 (0.96–1.02) All-cause mortality, RR 0.99 (0.97–1.00) |
| Chan and Ng | Chan and Ng (2011) | Taipei, Taiwan | All ages/all gender | PM$_{10}$ | Case-crossover/conditional logistic regression models | Non-accidental, respiratory, cardiovascular, deaths | Non-accidental deaths, OR 1.019 (1.003–1.035) Above 65 years old, OR 1.025 (1.006–1.044) Cardiovascular deaths, OR 1.045 (1.0011–1.081) Respiratory deaths, OR 0.988 (0.988–0.941) |
| Chen et al. | Chen et al. (2004) | Taipei, Taiwan | All ages/all gender | PM$_{10}$ | Case-crossover/tests of student | Daily mortality | Respiratory disease, RR 7.66% Total deaths, RR 4.92% Circulatory diseases, RR 2.59% |
| Crooks et al. | Crooks et al. (2016) | National/United States | All ages/all gender | PM$_{10}$ | Case-crossover/conditional logistic regression models | Daily non-accidental mortality | Non-accidental mortality 7.4% ($p = 0.011$) Lag$_{2-3}$ 6.7% ($p = 0.018$) Lag$_{0-2}$ 2.7% ($p = 0.023$) |
| Diaz et al. | Diaz et al. (2017) | Spain: 9 region | All ages/all gender | PM$_{10}$ | Longitudinal ecological time series/GAM | Daily mortality | Daily mortality values South-west, 21.20 (20.81–21.59) $p < 0.05$ South-east, 20.16 (19.88–20.45) $p < 0.05$ Canary Islands, 17.93 (17.60–18.26) $p < 0.05$ |
| Diaz et al. | Diaz et al. (2012) | Madrid (Spain) | All ages/all gender | PM$_{10}$ | Case-crossover design/Poisson regression model | Case-specific mortality | Respiratory death, IR 3.34% (0.36, 6.41) Circulatory causes, IR 4.19% (1.34, 7.13) |
| Hwang et al. | Hwang et al. (2004) | Seoul, Korea | All ages/all gender | PM$_{10}$ | Ecological time series/GAM | Daily non accidental deaths | Non accidental deaths, 1.7% (1.6 5.3) Aged 65 years and older, 2.2% (3.5 8.3) Cardiovascular and respiratory, 4.1% (3.8 12.6) |
| Jimenez et al. | Jimenez et al. (2010) | Madrid (Spain) | Elderly | PM$_{10}$, PM$_{2.5}$ or PM$_{0-2.5}$ | Ecological time series/Poisson regression models | Mortality | PM$_{10}$ Total mortality, lag$_{1}$ 1.02 (1.01–1.04) Circulatory, lag$_{1}$ 1.04 (1.01–1.06) Respiratory, lag$_{1}$ 1.03 (1.00–1.06) |
| Johnston et al. | Johnston et al. (2011) | Sydney, Australia | All ages/all gender | PM$_{10}$ | Case crossover/conditional logistic regression model | Non-accidental mortality | Non-accidental mortality, lag$_{p}$ OR 1.16 (1.03–1.30) |

(Continued)
| REFERENCE | FIRST AUTHOR AND YEAR | STUDY LOCATION | POPULATION (AGE, GENDER) | PM FRACTION | STUDY DESIGN/METHODOLOGY | HEALTH OUTCOMES | RESULTS |
|-----------|-----------------------|----------------|--------------------------|-------------|---------------------------|----------------|---------|
| Kashima et al. | Kashima et al. (2016) | South Korea and Japan | >65 years old/all gender | PM$_{10}$ | Ecological time-series analyses/specific Poisson regression models | Cause-specific mortality | All-cause mortality, lag$_{0}$ RR 1.003 (1.001 1.005) lag$_{1}$, 1.001 (1.000 1.003) Cerebrovascular disease, lag$_{0}$ RR: 1.006 (1.000 1.011) |
| Kashima et al. | Kashima et al. (2012) | Western Japan | Aged 65 or above | SPM | Ecological multi-city time-series analysis/Poisson regression models | Daily all-cause or cause-specific mortality | Heart disease, 0.6 (0.1 1.1) Ischemic heart disease, 0.8 (0.1 1.6) Arrhythmia, 2.1 (0.3 3.9) Pneumonia mortality, 0.5 (0.2 0.8) |
| Khaniabadi et al. | Khaniabadi et al. (2017) | Ilam (Iran) | – | PM$_{10}$ | Ecological time series/air Q model | Respiratory mortality | Respiratory Mortality 7.3 (4.9 19.5) |
| Kim et al. | Kim et al. (2012) | Seoul, Korea | General population/all gender | – | Ecological time-series/Poisson regression analyses | All-cause/cardiovascular mortality | The relative risk of total mortality for general population and over 75 years old increased on dusty days |
| Kwon et al. | Kwon et al. (2002) | Seoul, Korea | All ages/all gender | PM$_{10}$ | Ecological time series/GLM with Poisson regression | Non accidental deaths | All causes, RR 1.7% (1.6, 5.3) Persons aged 65 years older, RR 2.2% (3.5, 8.3) Cardiovascular and respiratory death, RR 4.1% (3.8, 12.6) |
| Lee et al. | Lee et al. (2014) | Seven metropolitan cities of Korea | All ages/all gender | PM$_{10}$ | Ecological time-series using/GAM with Quasi-Poisson distribution | Mortality | Seoul: Under 65 years old (lag$_{0}$: 4.44%, lag$_{1}$: 5%, and lag$_{2}$: 4.39%) Kitakyushu: Respiratory mortality (lag$_{0}$: 18.82%) Total non-accidental mortality (lag$_{0}$: −2.77%, lag$_{1}$: -3.24%) Taipei: Over 65 years old (lag$_{0}$: −3.35%, lag$_{1}$: −3.29%) Respiratory mortality (lag$_{0}$: −10.62%, lag$_{1}$: −9.67%) |
| Lee et al. | Lee et al. (2013) | Seven metropolitan cities of Korea | All ages/all gender | PM$_{10}$ | Ecological time-series/GAM with Quasi-Poisson regressions | Mortality | Lag$_{0}$ Cardiovascular: 2.91% (0.13, 5.77) Male: 2.74% (0.74, 4.77) Lag$_{1}$: <65 years, 2.52% (0.06, 5.04) Male 2.4% (0.43, 4.4) Lag$_{2}$: <65 years, lag$_{1}$: 2.49% (0.01, 4.97) Total non-accidental: 1.57% (0.11, 3.06) Male: 2.24% (0.28, 4.0) | |
| Lee et al. | Lee et al. (2007) | Seoul, Korea | All ages/all gender | PM$_{10}$ | Ecological time-series, GAM | Mortality | Total death, IR 0.7 (0.2, 1.3) (Continued) |

Table 1. (Continued)
| REFERENCE | FIRST AUTHOR AND YEAR | STUDY LOCATION | POPULATION (AGE, GENDER) | PM FRACTION | STUDY DESIGN/METHODOLOGY | HEALTH OUTCOMES | RESULTS |
|-----------|-----------------------|----------------|--------------------------|--------------|--------------------------|----------------|---------|
| Mallone et al. | Mallone et al. (2011) | Rome, Italy | ≥35 years/all gender | PM$_{2.5}$, PM$_{5.5-10}$, and PM$_{10}$ | Case-crossover/ Poisson regression model | Mortality | PM$_{2.5,15}$ Cardiac mortality, lag 0–2, IR 9.73 (4.25–15.49) Circulatory system, lag 0–2, IR 7.93 (3.20–12.88) PM$_{10}$ Cardiac mortality, lag 0–2, IR 9.55 (3.81–15.61%) |
| Perez et al. | Perez et al. (2008) | Barcelona (Spain) | All ages/all gender | PM$_{2.5}$ and PM$_{10-2.5}$ | Case-crossover/linear regression | Daily Mortality | PM$_{10-2.5}$ Daily mortality, Lag, OR 1.084 (1.015, 1.158) |
| Perez et al. | Perez et al. (2012) | Barcelona (Spain) | All ages/all gender | PM$_{1}$, PM$_{2.5}$ and PM$_{10}$ | Case–crossover/conditional logistic regression | Cause-specific mortality | PM$_{10-2.5}$ OR Cardiovascular mortality, (lag), 1.085 (1.01 1.15) $p < 0.05$ Respiratory mortality, (lag 2) 1.109 (0.978, 1.257) $p < 0.1$ PM$_{2.5-1}$ OR Cardiovascular mortality, (lag), 1.074 (0.998, 1.156) $p < 0.1$ |
| Renzi et al. | Renzi et al. (2018) | Sicily, Italy | All ages/all gender | PM$_{10}$ | Ecological time-series/Poisson conditional regression model | Mortality | Non-accidental mortality, (lag$_{0-5}$) IR 3.8% (3.2, 4.4) Cardiovascular, IR 4.5% (3.8, 5.3) Respiratory IR 6.3% (5.4, 7.2) |
| Pirsaheb et al. | Pirsaheb et al. (2016) | Kermanshah, Iran | All ages/all gender | PM$_{10}$ | Descriptive studies/ spearman test | Death from cardiovascular and respiratory disease | Increased dust concentrations increase the risk of cardiovascular mortality |
| Schwartz et al. | Schwartz et al. (1999) | Six United States. cities | All ages/gender | PM$_{10}$ | Ecological/GAM with Poisson regression | Mortality | Mortality, RR 0.99 (0.81–1.22) |
| Sajani et al. | Sajani et al. (2011) | Emilia-Romagna (Italy) | All ages/gender | PM$_{10}$ | Case-crossover/conditional logistic regression | Mortality | Respiratory mortality, OR 22.0 (4.0–43.1) Natural, OR 1.04 (0.99–1.09) Cardiovascular mortality, OR 1.04 (0.96–1.12) |
| Stafoggia et al. | Stafoggia et al. (2016) | Southern European cities-Spain, France, Italy, Greece | All ages/gender | PM$_{10}$ | Case-crossover/Poisson regression models | Mortality | Natural mortality lag$_{0-1}$ IR 0.65% (0.24–1.06) |
| Shahsavani et al. | Shahsavani et al. (2019) | Tehran and Ahvaz, IRAN | All ages/gender | PM$_{10}$ | Case crossover/conditional Poisson regression models | Mortality | Daily mortality 3.28 (2.42–4.15) |
| Tobias et al. | Tobias et al. (2011) | Madrid (Spain) | All ages/gender | PM$_{2.5}$ and PM$_{10-2.5}$ | Case-crossover/conditional logistic regression models | Mortality | PM$_{10-2.5}$ Each increase of 10 μg/m$^3$ of PM$_{10-2.5}$ increased Total mortality, 2.8% ($P = 0.01$) |
| Reference | First Author and Year | Study Location | Population (Age, Gender) | PM Fraction | Study Design/Methodology | Health Outcomes | Results |
|-----------|-----------------------|----------------|--------------------------|-------------|--------------------------|----------------|---------|
| Wang and Lin (2015) | Metropolitan Taipei | All ages/all gender | PM$_{10}$ | Ecological time series/distributed lag non-linear model | Mortality | All-cause mortality lag$_{0-5}$, RR 1.10 (1.04–1.17) Elderly mortality lag$_{0-5}$, RR 1.21 (1.02–1.44) |
| Samoli et al. (2011) | Athens, Greece | All ages/all gender | PM$_{10}$ | Ecological time series/Poisson regression models | Mortality | Mortality 0.71% (0.40–0.99) |
| Neophytou et al. (2013) | Nicosia, Cyprus | All ages/all gender | PM$_{10}$ | Ecological time-series/GAM | Mortality | Total non-accidental, IR 0.13% (1.03, 1.30) Cardiac mortality, IR 2.43 (0.53–4.37) Respiratory mortality, IR 0.79 (4.69, 3.28) |
| Goto et al. (2010) | Western Japan | All ages/all gender | -- | Ecological time-series/Spearman's rank correlation | Mortality | Asthma mortality ($r=0.268, n=8, P>0.05$) |
| Achilleos et al. (2019) | Kuwait | All ages/all gender | Poor visibility (AOD $>0.4$) | Ecological time-series/generalized additive model (GAM)/Poisson regression models | Mortality | Rate ratio: 1.02, (1.00–1.04) |
| Holyoak et al. (2011) | Queensland, Australia | -- | -- | Ecological retrospective review/simple t-test | Air medical retrieval service for respiratory and injury cases | Respiratory cases 62.5% increased Injury cases 13.3% increased |
| Aghababaeian et al. (2019) | Dezful, Iran | All ages/all gender | PM$_{10}$ | Ecological time-series/GAM | Emergency dispatch of cardiovascular, respiratory and traffic accident missions | RR of Emergency dispatch Lag$_{0}$ 1.008 (1.001–1.016)/female/18–60 years>60 years Lag$_{0}$ 1.008 (1.000–1.01) Lag$_{1}$ 1.008 (1.00–1.01) Lag$_{2}$ 1.008 (1.00–1.01) Lag$_{3}$ 1.007 (1.00–1.01) Lag$_{4}$ 1.006 (1.00–1.01) Lag$_{5}$ 1.06 (1.01–1.12) Lag$_{6}$ 1.09 (1.01–1.17) >60 years 1.28 (1.08–1.52) Cardiovascular Problems Lag$_{0-5}$ 1.33 (1.17–1.50) Respiratory problems Lag$_{0-5}$ 1.13 (0.93–1.38) Traffic Accident Trauma Lag$_{0-5}$ 1.03 (0.94–1.13) |

(Continued)
| Reference | First Author and Year | Study Location | Population (Age, Gender) | PM Fraction | Study Design/Methodology | Health Outcomes | Results |
|-----------|-----------------------|----------------|--------------------------|-------------|--------------------------|----------------|---------|
| Kashima et al. (2014) | Okayama, Japan | Elderly people | SPM | Ecological time-series/Poisson regression with GAM | Emergency ambulance calls | All causes, Lag 0 1.009 (1.002–1.017) Cardiovascular, lag 0–3 1.02 (1.00–1.03) Cardiovascular, Lag 0–9 1.016 (1.001–1.032) Cerebrovascular, Lag 0–9 1.028 (1.007–1.049) Pulmonary, Lag 0–9 1.005 (0.986–1.025) |
| Ueda et al. (2012) | Nagasaki, Japan | All ages/gender | SPM | Case-crossover/conditional logistic regression | Emergency ambulance dispatches | All causes lag 0–3 12.1% (2.3–22.9) Cardiovascular diseases 20.6% (3.5–40.9) |
| Akpinar-Elci et al. (2015) | Grenada, Caribbean | All ages/gender | – | Ecological/regression analysis | Asthma visits | Asthma (R²=0.036, p < 0.001) |
| Cadelis et al. (2014) | Guadeloupe (Caribbean) | Children/all gender | PM₁₀, PM₂.5–₁₀ | Case-crossover/t-test and Mann-Whitney | Visits of children due to asthmatic conditions | PM₁₀ Lag 0 IR 9.1% (7.1–11.1) Lag 0–1 IR 5.1% (1.8–7.7) PM₂.5–₁₀ Lag 0 IR 4.5% (3.3–5) Lag 0–1 IR: 4.7% (2.5–6.5) |
| Carlsten et al. (2015) | Reykjavik, Iceland | All ages/gender | PM₁₀ | Ecological time-series study/generalized additive regression model | Emergency hospital visits | Emergency hospital visits 5.8% (p=0.02) |
| Chan et al. (2008) | Taipei, Taiwan | All ages/gender | PM₁₀ | Ecological time-series/Poisson regression model and paired t-test | Emergency visits | Cardiovascular visits 1.5 (0.3–2.6) Ischemic heart diseases visits 0.7 (0.1–1.4) Cerebrovascular visits 0.7 (0.1–1.3) Chronic obstructive pulmonary disease (COPD) visits 0.9 (0.1–1.7) |
| Chien et al. (2014) | Taipei, Taiwan | Children | PM₁₀ | Ecological studies/structural additive regression modeling | Conjunctivitis clinic visits | Conjunctivitis visits Preschool children 1.48% (0.79, 2.17) Schoolchildren. 9.48% (9.03, 9.93) |
| Chien et al. (2012) | Taipei, Taiwan | Children | PM₁₀ | Ecological/STAR model and autoregressive correlation | Respiratory diseases visits | Respiratory visits Preschool children 2.54% (2.43, 2.66) Schoolchildren 5.03% (4.87, 5.20) |
| Hefflin et al. (1994) | Washington, United States | All ages/gender | PM₁₀ | Ecological/multivariable analysis using generalized estimating equations | Emergency room visits for respiratory disorders | Daily number of emergency visits for bronchitis, IR 3.5% Daily Number of emergency room visits, IR 4.5% |
| Lin et al. (2016) | Taipei, Taiwan | All ages/gender | PM₁₀ | Ecological time series/DLNM | Emergency room visits | All causes visits, RR 1.10 (1.07, 1.13) Respiratory visits, RR 1.14 (1.08, 1.21) |
| Reference       | First Author                  | Study Location     | Population (Age, Gender) | PM Fraction | Study Design/Methodology                     | Health Outcomes                        | Results                                      |
|-----------------|-------------------------------|--------------------|--------------------------|-------------|-----------------------------------------------|-----------------------------------------|----------------------------------------------|
| Liu and Liao149 | Liu and Liao (2017)           | Taiwan             | All ages/all gender      | PM$_{2.5}$  | Case-crossover/conditional logistic regression| Emergency visits                        | Cardiovascular, OR 2.92 (1.22–5.08) Respiratory, OR 1.86 (1.30–2.91) |
| Merrifield et al.141 | Merrifield et al. (2013) | Sydney, Australia | All ages/all gender      | PM$_{10}$   | Ecological time-series/distributed-lag Poisson generalized models | Emergency visits                        | Asthma visits, RR 1.23, (p < 0.01) All visits, R 1.04, (p < 0.01) Respiratory visits, RR 1.20, (p < 0.01) Cardiovascular visits, RR 0.91, (p = 0.09) |
| Nakamura et al.139 | Nakamura et al. (2016)    | Nagasaki, Japan    | Children aged 0–15 years/all gender | SPM         | Case-crossover/conditional logistic models    | Pediatric emergency visits for respiratory diseases | School children Bronchial asthma visits, lag$_0$ OR 1.83 (1.212–2.786) Lag$_1$ 1.829 (CI 1.179–2.806) Preschool children Respiratory visit, lag$_0$ OR 1.244 (1.128–1.373) Lag day 1, OR 1.314 (1.189–1.452) Lag day 2, OR 1.273 (1.152–1.408) |
| Park et al.62   | Park et al. (2015)            | Chuncheon, Gangwon-do, Korea | All ages/all gender      | PM$_{10}$   | Ecological retrospective study/Poisson regression model | Hospital visits for airway diseases       | Asthma visits, RR 1.10 (P < 0.05) COPD visits, RR 1.29 (P < 0.05) |
| Wang et al.63   | Wang et al. (2016)            | Minquin, China     | All ages/all gender      | --          | Ecological time series/generated regression model | Pulmonary tuberculosis (PTB) visits       | PTB visits, R$^2 = 0.685$ |
| Park et al.140  | Park et al. (2016)            | Seoul and Incheon, Korea | 11–20, 51–70 and 490 years/all gender | PM$_{10}$   | Case-crossover/T-tests and Poisson regression model | Asthma exacerbation                       | Asthma related visits Lag$_0$, RR 0.96 (0.95–0.98) Lag$_1$, RR 1.27 (1.25–1.29) Lag$_2$, RR 1.12 (1.10–1.14) Lag$_3$, RR 1.25 (1.23–1.26) Lag$_4$, RR 1.13(1.12–1.15) Lag$_5$, RR 1.06 (1.04–1.07) Lag$_6$, RR 0.82 (0.81–0.81) |
| Yu et al.12     | Yu et al. (2012)              | Taipei (Taiwan)    | Children                 | PM$_{10}$   | Ecological studies/STAR model/generalized additive mode | Children’s respiratory health risks       | All children Lag$_0$ ~3.66 Lag$_1$ ~2.05 Lag$_2$ 1.78 Lag$_3$ 2.40 Lag$_4$ 0.66 Lag$_5$ 1.74 Lag$_6$ ~1.01 Lag$_7$ 2.26 |

(Continued)
| REFERENCE | FIRST AUTHOR AND YEAR | STUDY LOCATION | POPULATION (AGE, GENDER) | PM FRACTION | STUDY DESIGN/ METHODOLOGY | HEALTH OUTCOMES | RESULTS |
|-----------|-----------------------|----------------|-------------------------|-------------|---------------------------|----------------|---------|
| Yang545   | Yang (2006)           | Taipei, Taiwan | All ages/all gender     | PM_{10}     | Case-crossover/ Poisson regression model | Conjunctivitis visit | Lag_0 RR 1.02 (0.88–7.99) |
|           |                       |                |                         |             |                           |                 | Lag_7 RR 0.99 (0.86–7.46) |
|           |                       |                |                         |             |                           |                 | Lag_1 RR 0.95 (0.83–6.93) |
|           |                       |                |                         |             |                           |                 | Lag_2 RR 0.97 (0.85–7.11) |
|           |                       |                |                         |             |                           |                 | Lag_3 RR 1.11 (0.97–9.41) |
|           |                       |                |                         |             |                           |                 | Lag_4 RR 0.95 (0.84–6.86) |
| Lorentzou  | Lorentzou et al.      | Heraklion in Crete Island, Greece | All ages/all gender | PM_{10}     | Ecological retrospective analysis/ one-way ANOVA and Pearson Correlation | Emergency department visits | Correlation All cases 0.313 p = 0.128 |
| et al.122  | (2019)                |                |                         |             |                           |                 | Allergy cases 0.929 p = 0.000 |
|           |                       |                |                         |             |                           |                 | Dyspnea cases 0.464 p = 0.041 |
| Trianti et | Trianti et al.        | Athens, Greece | Aged 18 years and Upper/all gender | PM_{10}     | Ecological study/ mixed Poisson model | Respiratory morbidity/emergency room visits | Respiratory visits, IR 1.95% (0.02, 3.91) |
| al.52      | (2017)                |                |                         |             |                           |                 | Asthma visits, IR 38% (p < 0.001) |
|           |                       |                |                         |             |                           |                 | COPD visits, IR 57% (p < 0.001) |
|           |                       |                |                         |             |                           |                 | Respiratory infections visits, IR 60% (p < 0.001) |
| Yang et al.| Yang et al.           | Wuwei, China   | All ages/ all gender    | PM_{2.5}    | Ecological time-series/GAM | Respiratory and cardiovascular outpatient visits | Respiratory outpatient Male, RR 1.217 (1.08, 1.606) |
| 150       | (2015)                |                |                         |             |                           |                 | Female, RR 1.175 (1.025, 1.347) |
|           |                       |                |                         |             |                           |                 | Cardiovascular outpatient Male, RR 1.146 (1.056, 1.243) |
|           |                       |                |                         |             |                           |                 | Female, RR 1.105 (1.017, 1.201) |

**Long-term health effects**

| Altindag et | Altindag et al.      | Korea | Infant | PM_{10} | Cohort/linear regression models | Birth weight, a binary indicator of low birthweight, gestation, premature birth, and fetal growth | Birth Weight, _0.232 (P = 0.10) |
| al.52       | (2017)                |       |        |         |                           |                           | Low birth weight, 0.0001 (P = 0.000) |
| Dadvand et  | Dadvand et al.        | Barcelona/Spain | Pregnant woman | PM_{10} | Cohort/linear regression models-logistic regression model | Pregnancy complications | Birth weight −2.1 (−5.8, 1.7) |
| al.169      | (2011)                |       |        |         |                           |                           | Gestation 0.5 (0.4, 0.6) |
| Li et al.   | Li et al. (2018)      | Between northern and southern China. | Aged 10–15 years, all gender | – | Cohort/fixed-effect model | Children's cognitive function | Reduction in word scores, 0.20 (0.06, 0.35) |
|            |                       |       |        |         |                           |                           | Reduction in mathematics scores 0.18 (0.10, 0.25) |
| Viel et al. | Viel et al.           | Guadeloupe (French West Indies) | 909 pregnant women | PM_{10} | Cohort/multivariate logistic regression models | Preterm births | OR 1.40, (1.08–1.81) |

(Continued)
| REFERENCE         | FIRST AUTHOR AND YEAR | STUDY LOCATION | POPULATION (AGE, GENDER) | PM FRACTION | STUDY DESIGN/METHODOLOGY | HEALTH OUTCOMES | RESULTS |
|-------------------|-----------------------|----------------|--------------------------|-------------|--------------------------|----------------|---------|
| Tong et al. 36    | Tong et al. (2017)    | Southwestern United States | All ages/all gender | PM₁₀ | Research letter/correlation coefficient | Valley fever | Correlation coefficient Maricopa, 0.51 Pima, 0.36–0.41 |
| Ma et al. 44      | Ma et al. (2017)      | Western China | All ages/all gender | TSP, PM₁₀ | Ecological time series/Pearson correlation coefficient | Measles incidence | The correlation coefficient for TSP Entire Lanzhou city, 0.291 Downtown Lanzhou, 0.346 The correlation coefficient for PM₁₀ Entire Lanzhou city, 0.260 Downtown Lanzhou, 0.342 Dust events, Excess measles Zhangye, 39.1 (17.3–67.6) Lanzhou, 149.9 (7.1–413.4) Jiuquan, 31.3 (20.6–63.5) |

**Hospitalization or admission**

| Aili and Oanh 91  | Aili and Oanh (2015) | China/Taklimakan Desert | All ages/all gender | TSP | Ecological time series/GAM | Respiratory outpatients, RR 1.01 (1.00–1.02) Respiratory inpatients, RR 0.99 (0.99–1.00) Digestion outpatients, RR 1.005 (0.99–1.01) Digestion inpatients, RR 1.001 (0.999–1.002) Circulatory outpatients, RR 1.010 (1.003–1.016) Circulatory inpatients, RR 1.001 (0.999–1.002) Gynecology outpatients, RR 1.008 (1.002–1.014) Gynecology inpatients, RR 0.999 (0.997–1.001) Pediatrics outpatients, RR 1.010 (1.002–1.018) Pediatrics Inpatients, RR 1.001 (0.999–1.002) ENT outpatients, RR 1.007 (1.002–1.012) ENT inpatients, RR 1.002 (0.998–1.004) |
| Al et al. 86      | Al et al. (2018)      | Gaziantep/Turkey | Older than 16 years | PM₁₀ | Retrospective study/GAM | Morbidity of cardiovascular diseases admitted to emergency department | Congestive cardiac failure admission, OR 1.003 (0.972–1.036) Hospitalization, OR 2.209 (2.069–2.359) Acute coronary syndrome admission, OR 1.150 (1.135–1.166) Hospitalization, OR 1.304 (1.273–1.336) |
| Alangari et al. 126 | Alangari et al. (2015) | Riyadh, Saudi Arabia | Children 2–12 years | PM₁₀ | Ecological/correlation coefficient | Patient presented to the emergency department (ED) with acute asthma | Acute asthma, r = −0.14, (P = 0.45) Admission rate, r = −0.08, (P = 0.65) |

(Continued)
| **REFERENCE** | **FIRST AUTHOR AND YEAR** | **STUDY LOCATION** | **POPULATION (AGE, GENDER)** | **PM FRACTION** | **STUDY DESIGN/ METHODOLOGY** | **HEALTH OUTCOMES** | **RESULTS** |
|---------------|--------------------------|--------------------|-----------------------------|----------------|-----------------------------|--------------------|-------------|
| Alessandrini et al. (2013) | Rome, Italy | Less than 14 years or 35 years or more | PM$_{2.5}$, PM$_{10}$, and PM$_{10}$ | Ecological time-series/GAM | Respiratory, cardiac and cerebrovascular hospitalizations | PM$_{2.5}$ Cardiac diseases, lag$_{0-1}$: 2.41 (−0.21, 5.09) Cerebrovascular diseases, lag$_{0}$: −2.14 (−4.73, 0.53) Respiratory diseases, lag$_{0-5}$: −0.52 (−5.33, 4.53) Respiratory diseases, lag$_{0-5}$: −2.14 (−9.09, 5.35) PM$_{2.5-10}$ (IR) Cardiac diseases, lag$_{0-1}$: 3.93 (1.58, 6.34) Cerebrovascular diseases, lag$_{0}$: 1.68 (−0.70, 4.11) Respiratory Diseases, lag$_{0-4}$: 4.77 (−0.57, 10.40) Respiratory diseases lag$_{0-14}$: −1.20 (−8.52, 6.71) PM$_{10}$ Cardiac diseases, lag$_{0-1}$: 3.37 (1.11, 5.68) Cerebrovascular diseases, lag$_{0}$: 2.64 (0.06, 5.29) Respiratory Diseases, lag$_{0-5}$: 3.59 (0.18, 7.12) Respiratory diseases, lag$_{0-14}$: −0.04 (−4.64, 4.78) |
| Al-Hemoud et al. (2018) | Kuwait | All ages/all gender | PM$_{10}$ | Ecological time series/GAM | Daily morbidity | Bronchial asthma, $r = 0.292$ Respiratory infection Lower, $r = 0.737$ upper, $r = 0.839$ |
| Al-Taair (2012) | Kuwait | All ages/all gender | PM$_{10}$ | Ecological time series generalized/GAM | Daily emergency admissions due to asthma and respiratory causes | Asthma admission, RR 1.07 (1.02–1.12) Respiratory admission, RR 1.06 (1.04–1.08) |
| Barnett (2012) | Brisbane, Australia | All ages/all gender | PM$_{10}$ | Ecological time series/Poisson regression model | Emergency admissions to hospital | Emergency admissions 39% (5, 81%) |
| Bell et al. (2008) | Taipei, Taiwan | All ages/all gender | PM$_{10}$ | Ecological time series/Poisson time-series model | Cause-specific hospital admissions | Ischemic heart disease, Lag$_{1}$ 16.17 (1.17, 33.39) |
| Chan et al. (2018) | Nationwide/Taiwan | All ages/all gender | Total atmospheric PM | Ecological time series/auto-regressive model-ARMAX regression | Diabetes hospitalization | Diabetes lag$_{1}$ 27.41 ($p = 0.04$) |
| Chen and Yang (2005) | Taipei, Taiwan | All ages/all gender | PM$_{10}$ | Case-crossover/tests of student | Daily hospital admissions for cardiovascular disease (CVD) | CVD, lag$_{1}$ RR (3.65%) $P > 0.05$ |
| REFERENCE     | FIRST AUTHOR AND YEAR | STUDY LOCATION       | POPULATION (AGE, GENDER) | PM FRACTION | STUDY DESIGN/ METHODOLOGY                                      | HEALTH OUTCOMES                      | RESULTS                                                                 |
|--------------|-----------------------|----------------------|-------------------------|-------------|-----------------------------------------------------------------|--------------------------------------|-------------------------------------------------------------------------|
| Cheng et al. | Cheng et al. (2008)   | Taipei, Taiwan       | All ages/all gender     | PM$_{10}$   | Case-crossover/ Poisson regression models                       | Daily pneumonia hospital admissions | Pneumonia admissions lag$_0$ RR 1.03 (0.98–1.08) lag$_1$ RR 1.04 (1.00–1.09) lag$_2$ RR 1.04 (0.99–1.09) lag$_3$ RR 1.03 (0.99–1.08) |
| Chiu et al.  | Chiu et al. (2008)    | Taipei, Taiwan       | All ages/all gender     | PM$_{10}$   | Case-crossover/ Poisson regression models                       | COPD admissions                      | COPD, Lag$_3$, RR 1.057; (0.982–1.138)                                    |
| Dong et al.  | Dong et al. (2007)    | large cities of Korea| All ages/all gender     | PM$_{10}$   | Ecological/correlation coefficients                             | Hospitalization                      | Seoul 0.652 Busan 0.377 Daegu 0.681 Incheon 0.736 Kwangju 0.481 Daejeon 0.652 Uisan 0.702 Jeju-do 0.129 |
| Ebenstein et al. | Ebenstein et al. (2015) | Israel, Jerusalem and Tel Aviv | All ages/all gender | PM$_{10}$   | Ecological/IV methodology/Poisson regression approach          | Respiratory hospital admissions      | Respiratory admissions IR 0.8% COPD 0.01 (0.003) Asthma 0.008 (0.003) Respiratory abnormalities 0.006 (0.002) |
| Ebrahimi et al. | Ebrahimi et al. (2014) | Sanandaj, Iran       | All ages/ all gender    | PM$_{10}$   | Ecological/Pearson’s correlation coefficient, linear regression model | Emergency admissions for cardiovascular and respiratory diseases | Cardiovascular 0.48 (P < 0.05) Respiratory patients 0.19 (P > 0.05) |
| Geravandi et al. | Geravandi et al. (2017) | Ahvaz/Iran           | All ages/all gender     | PM$_{10}$   | Ecological/non-parametric Mann-Whitney U test/ correlation coefficients | Hospital admissions for Respiratory diseases | Respiratory diseases ($r=0.53$)                                               |
| Grineski et al. | Grineski et al. (2011) | El Paso, Texas, United Stats | All ages/all gender | PM$_{2.5}$  | Case-crossover/-conditional logistic regression                 | Hospital admissions for Asthma and Acute bronchitis | Asthma 1.11 (0.96–1.28) All ages 1.23 (0.99–1.55)                         |
| Kamouchi et al. | Kamouchi et al. (2012) | Fukuoka, Japan       | 20 years and older/all gender | –           | Case-crossover/ conditional logistic regression                 | Ischemic stroke                       | Overall///Atherothrombotic ZD7 lag$_{-1}$, OR 1.07 0.93–1.23///1.44 1.08–1.91 lag$_{-2}$, OR 1.04 0.97–1.18///1.48 1.14–1.93 lag$_{-3}$, OR 1.02 0.90–1.15///1.37 1.06–1.76 lag$_{-4}$, OR 1.02 0.90–1.14///1.35 1.06–1.73 lag$_{-5}$, OR 1.02 0.91–1.15///1.35 1.06–1.72  |
| Kanatani et al. | Kanatani et al. (2010) | Toyama, Japan        | Children                | –           | Case-crossover/ generalized estimating equations logistic and Conditional logistic regression | Asthma hospitalization                | OR 1.88 (1.04–3.41; P 5 0.037)                                           |

(Continued)
| Study | First Author(s) | Year | Location | Population (Age, Gender) | PM Fraction | Study Design/Methoogy | Health Outcomes | Results |
|-------|----------------|------|----------|--------------------------|-------------|-----------------------|-----------------|---------|
| Kang et al. | 2012 | Taipei, Taiwan | All ages/all gender | | PM$_{10}$ | Ecological time series/Kruskal–Wallis test/auto-regressive integrated moving average (ARIMA) method | Pneumonia hospitalization | Pneumonia admissions (239.6, post-DS days) |
| Kang et al. | 2013 | Taiwan | All ages/all gender | | PM$_{10}$ | Ecological time series/ARIMA method (auto-regressive integrated moving average) | Stroke hospitalization | Stroke admissions (239.6, post-DS days) |
| Kashima et al. | 2017 | Okayama, Japan | Elderly | | SPM | Case-crossover/conditional logistic regression analyses | Susceptibility of the elderly to disease | Respiratory OR: 1.09 (1.00, 1.19), Cardiovascular OR: 0.97 (1.01, 1.15) |
| Khaniabadi et al. | 2017 | Ilam, Iran | All ages/all gender | | PM$_{10}$ | Ecological time series/AirQ model | Hospitalizations for chronic obstructive pulmonary disease (COPD) | Respiratory admissions |
| Ko et al. | 2016 | Fukuoka, western Japan | Men, Women ratio 30.15, Age 49.6 ± 22.7 | | PM$_{10}$ | Cohort design/t-test | Acute conjunctivitis | Conjunctivitis scores P < 0.05 |
| Kojima et al. | 2017 | Kumamoto, Japan | 20 years of age or older/all gender | | PM$_{10}$ | Case-crossover/Z test | Acute myocardial infarction (AMI) | AMI OR: 1.46 (0.99–2.19), Non ST-segment OR: 2.6 (2.1–3.15) |
| Lee and Lee | 2017 | Seoul, Korea | All ages/all gender | | PM$_{10}$ | Case-control/test | Respiratory admissions | Respiratory admissions |
| Lorentzou et al. | 2019 | Heraklion in Crete Island, Greece | All ages/all gender | | PM$_{10}$ | Ecological time series/patterns/panel test | Daily asthma patients | COPD exacerbations, 3.0 (0.8–5.2) |

(Continued)
| REFERENCE       | FIRST AUTHOR AND YEAR | STUDY LOCATION | POPULATION (AGE, GENDER) | PM FRACTION | STUDY DESIGN/METHODOLOGY | HEALTH OUTCOMES | RESULTS |
|-----------------|-----------------------|----------------|--------------------------|-------------|--------------------------|----------------|---------|
| Matsukawa et al.| Matsukawa et al. (2014)| Fukuoka, Japan | Patients aged ≥20 years/all gender | SPM         | Case-crossover/conditional logistic regression model | Incidence of acute myocardial infarction | AMI Lag OR 1.33 (1.05–1.69), Lag OR 1.20 (1.02–1.40) |
| Menendez et al. | Menendez et al. (2017) | Gran Canaria, Spain | Adults (age 14–80 years) and ≥80/all gender | PM10       | Epidemiological survey/(ANOVA) and Spearman correlation coefficients (ρ) | Health condition of the allergic population | ρ (p-values): Pneumonia 0.2 (0.5), Asthma 0.8 (0.0), COPD 0.0 (1.0) |
| Meng and Lu    | Meng and Lu (2007)     | Minquín, China | All ages/all gender       | –           | Ecological time-series/GAM | Daily hospitalization for respiratory and cardiovascular diseases | Respiratory hospitalization, lag3 RR Male 1.14 (1.01–1.29), Female 1.18 (1.00–1.41), Respiratory infection, Male, RR 1.28 (1.04–1.59), Pneumonia, Lag Males, RR 1.17 (1.00–1.38), Hypertension, Lag2 Males, RR 1.30 (1.03, 1.64) |
| Middleton et al.| Middleton et al. (2008)| Nicosia, Cyprus | All ages/all gender       | PM10       | Ecological time-series/GAM | Respiratory and cardiovascular morbidity | All-cause 4.8% (0.7, 9.0), Cardiovascular 10.4% (4.7, 27.9) |
| Nakamura et al. | Nakamura et al. (2015) | All-Japan       | All ages/all gender       | SPM         | Case-crossover/conditional logistic models | Out-of-hospital cardiac arrests | Model 1 1.00 (0.97–1.19), Model 2 1.08 (0.97–1.20) |
| Nastos, et al. | Nastos, et al. (2011)  | Crete Island, Greece | All ages/all gender       | –           | Ecological time-series-HYSPLIT 4 model of air resources laboratory of NOAA | Cardiovascular and respiratory syndromes | Respiratory five-fold increased, Cardiovascular didn’t increased significant |
| Pirsaheb et al. | Pirsaheb et al. (2016) | Kermanshah, Iran | All ages/all gender       | PM10       | Ecological/regression | Respiratory disease | Respiratory infection P = 0.05, Chronic pulmonary disease P = 0.05, COPD P > 0.05, Angina P > 0.05, Asthma P > 0.05 |
| Prospero et al. | Prospero et al. (2008) | Caribbean       | Aged 18 years and under/all gender | –           | Ecological time series/ Mann–Whitney rank-sum test, two-tailed | Pediatric asthma | Pediatric asthma, P > 0.05 |
| Radmanesh et al.| Radmanesh et al. (2019) | Abadan, Iran    | All ages/all gender       | PM10       | Ecological studies/Pearson coefficient | Hospital admission for cerebral ischemic attack, epilepsy and headaches | Cerebral ischemic attack, r: 0.113 p = 0.3, Epilepsy, r: 0.492 p = 0.03, Headaches, r: 0.009 p = 0.9 |
| Reyes et al.   | Reyes et al. (2014)    | Madrid (Spain)  | All ages/all gender       | PM10-2.5   | Ecological time series/conditional logistic regression model | Hospital admissions | Respiratory admissions, Lag, RR 1.031 (1.002 1.060) |

(Continued)
| Reference | First Author and Year | Study Location | Population (Age, Gender) | PM Fraction | Study Design/Methodology | Health Outcomes | Results |
|-----------|-----------------------|----------------|--------------------------|-------------|--------------------------|----------------|---------|
| Rutherford, et al. (1999) | | Brisbane, Australia | All ages/all gender | TSP | Cross-sectional/paired two-tailed t-tests | Impact on asthma severity | Asthma severity, P ≤ 0.05 In General P > 0.05 |
| Stafoggia et al. (2016) | | Southern European cities-Spain, France, Italy, Greece | All ages/all gender | PM10 | Case-crossover/Poisson regression model | Hospital admissions | Admissions, IR Cardiovascular, age ≥15 0.32 (−0.24, 0.89) Respiratory, age ≥15 0.70 (−0.45, 1.87) Respiratory, age 0–14 2.47 (0.22, 4.77) |
| Tam et al. (2012) | | Hong Kong | All ages/all gender | PM10-2.5 | Case-crossover/t-test/Poisson regression model | Daily emergency admissions for cardiovascular diseases | PM10–2.5 Ischemic heart disease, RR 1.04 (1.00, 1.08) |
| Tao et al. (2012) | | Lanzhou, China | All ages/all gender | PM10 | Ecological/Poisson regression model into GAM model | Respiratory diseases admissions | Respiratory hospitalizations, RR Male, 1.148 P > 0.05 Female 1.144 P > 0.05 |
| Teng et al. (2016) | | Taipei, Taiwan | All ages/all gender | PM10 | Ecological time series/autoregressive with exogenous variables model | Daily acute myocardial infarction hospital admissions | AMI hospitalizations, 3.2 more |
| Thalib and Al-Ta’i (2012) | | Kuwait | All ages/all gender | PM10 | Ecological time series study/GAM | Asthma admissions | Asthma, RR 1.07 (1.02–1.12) Respiratory admission, RR 1.06 (1.04–1.08) |
| Ueda et al. (2010) | | Fukuoka, Japan | children under 12 years of age/all gender | SPM | Case-crossover/conditional logistic regression | Hospitalization for asthma | Asthma hospitalization, lag0–3 OR 1.041 (1.013–1.070) |
| Vodonos et al. (2014) | | Be’er Sheva, Israel | All ages/all gender | PM10 | Ecological time series/GAM | Hospitalizations due to exacerbation of COPD | COPD exacerbation: IR 1.16 (p < 0.001) |
| Vodonos et al. (2015) | | Be’er Sheva, Israel | Above 18 years old/all gender | PM10 | Case crossover/GAM | Cardiovascular Morbidity | Acute coronary syndrome (lag1); OR = 1.007 (1.002–1.012). |
| Wang et al. (2014) | | Taiwan | All ages/all gender | PM10 | Ecological time series/ARIMAX regression model | Asthma admissions | Asthma, Lag0–3 average of 17–20 (p < 0.05) more hospitalized |
| Wang et al. (2015) | | Minquin County, China | Above 40 years old/all gender | – | Case-control/comparison/Student’s t-test | Human respiratory system | Chronic rhinitis, OR 3.14 (1.77–5.55) Chronic bronchitis, OR 2.46 (1.42–4.28) Chronic cough, OR 1.78 (1.24–2.56) |
| Watanabe et al. (2014) | | Western Japan | Aged ≥18 years old/all gender | SPM | Descriptive/telephone survey/t-test. Multiple regression analysis | Worsening asthma | Worsening asthma 11–22% Pulmonary function of asthma patients −0.367 p = 0.003 |
| REFERENCE | FIRST AUTHOR AND YEAR | STUDY LOCATION | POPULATION (AGE, GENDER) | PM FRACTION | STUDY DESIGN/ METHODOLOGY | HEALTH OUTCOMES | RESULTS |
|-----------|-----------------------|----------------|--------------------------|-------------|---------------------------|-----------------|---------|
| Yang et al.134 Yang et al. (2005) | Taipei, Taiwan | All ages/all gender | PM$_{10}$ | Case-crossover/ Poisson regression model | Stroke admissions | Hemorrhagic stroke, Lag$_1$ RR 1.15 (1.01–1.10) |
| Yang et al.102 Yang et al. (2009) | Taipei, Taiwan | All ages/all gender | PM$_{10}$ | Case-crossover/ Poisson regression model | Hospital admissions for congestive heart failure | CHF, Lag$_3$ RR 1.14 (0.993–1.250) |
| Yang et al.116 Yang et al. (2005) | Taipei, Taiwan | All ages/all gender | PM$_{10}$ | Case-crossover studies/Poisson regression model | Daily admissions for asthma | Asthma lag$_8$ 8% (p > 0.05) |
| Al et al.86 Al et al. (2018) | Gaziantep, Turkey | All ages/all gender | PM$_{10}$ | Retrospective study/ GAM | Cardiovascular diseases admitted to ED | Cardiac failure, OR Admission 1.003 (0.972–1.036) P = 0.833 Hospitalization 2.209 (2.069–2.359) P = 0.001 |
| Gyan et al.112 Gyan et al. (2005) | Caribbean island of Trinidad | Patients aged 15 years and under | – | Ecological/Poisson regression model | Pediatric asthma accident and emergency admissions | Admission rate increased 7.8–9.25 |
| Bennett et al.105 Bennett et al. (2006) | Lower Fraser Valley, British Columbia, Canada | All ages/all gender | PM$_{10}$ | Ecological time-series/Chi-squared | Hospital admissions | Hospitalizations Respiratory 0.89, χ$^2$ = 0.71 Cardiac 0.91, χ$^2$ = 0.54 |
| Cheng et al.55 Cheng et al. (2008) | Taipei, Taiwan | All ages/all gender | PM$_{10}$ | Case-crossover/ Poisson regression model | Daily pneumonia hospital admissions | Pneumonia admissions, RR 1.032 (0.980–1.086) Lag$_1$ 1.049 (1.002–1.098) Lag$_3$ 1.044 (0.999–1.092) Lag$_5$ 1.037 (0.993–1.084) |
| Wilson et al.124 Wilson et al. (2012) | Hong Kong | All ages/all gender | PM$_{10}$ | Case-crossover/ Poisson regression model | Daily emergency admissions for respiratory diseases | COPD, lag$_2$ RR 1.05 (1.01–1.09) |
| Wiggs et al.130 Wiggs et al. (2003) | Karakalpakstan, Uzbekistan | Children/all gender | PM$_{10}$ | Ecological | Respiratory health | Decreased the rate of respiratory health problems |
| Pulmonary function | | | | | | |
| Hong et al.100 Hong et al. (2010) | Seoul, Korea | Children/all gender | PM$_{2.5}$ and PM$_{10}$ | Prospective/linear mixed-effects mode | Pulmonary function of school children | PM$_{2.5}$ (P > 0.05) PM$_{10}$ (P > 0.05) |
| Kurai et al.157 Kurai et al. (2017) | Yonago, Tottori, western Japan | School children/ adults | PM$_{2.5}$ | Descriptive/ longitudinal/ Linear mixed models | Respiratory function | Lag$_{9-20}$ -1.76 (−3.30, −0.21) Lag$_{9-20}$ -1.54 (−2.84, −0.25) Lag$_{9-20}$ -1.05 (−2.21, 0.11) Lag$_{9-20}$ -1.09 (−2.18, −0.01) |

(Continued)
| Reference | First Author and Year | Study Location | Population (Age, Gender) | PM Fraction | Study Design/Methodology | Health Outcomes | Results |
|-----------|-----------------------|----------------|--------------------------|-------------|-------------------------|----------------|---------|
| Watanabe et al. (2016) | Watanabe et al. | western Japan | Schoolchildren | SPM | A panel study/linear mixed models | Pulmonary function | Peak expiratory flow (PEF) \(-3.62 (-4.66, -2.59)\) |
| Watanabe et al. (2015) | Watanabe et al. | western Japan | Schoolchildren | SPM | Longitudinal follow-up study/linear mixed models | Pulmonary function | PEF 2012 \(-8.17 (-11.40, -4.93)\) 2013 \(-1.17 (-4.07, 1.74)\) |
| Yoo et al. (2008) | Yoo et al. | Seoul, Korea | Children | PM\(_{2.5}\) | Prospective/Pearson correlation tests/paired t-test | Respiratory symptoms and peak expiratory flow | PEF decreased \(p < 0.05\) |
| Watanabe et al. (2016) | Watanabe et al. | Western Japan | Aged 18 years | SPM | Panel study/linear mixed models | Pulmonary function | PEF, in allergic patients with Asthma \(-16.3 (-32.9, 0.4) P = 0.06\) Rhinitis \(-7.0 (-19.5, 5.5) P = 0.27\) Conjunctivitis \(-3.9 (-38.8, 30.9) P = 0.83\) Dermatitis \(-5.6 (-21.3, 10.2) P = 0.49\) Food allergy \(0.4 (-23.3, 23.9) P = 0.98\) |
| Watanabe et al. (2015) | Watanabe et al. | Western Japan | Aged \(>18\) years | SPM | Panel study study/linear regression analysis | Pulmonary function in adult with asthma | PEF 0.01 \((-0.62, 0.11)\) |
| Park et al. (2005) | Park et al. | Incheon, Korea | Ages of 16 and 75 years/ all gender | PM\(_{10}\) | Cohort/t-test/GAM with Poisson log-linear regression | Peak expiratory flow rates and respiratory symptoms of asthmatics | PEF 1.05 \(0.89-1.24\) |
| O’Hara et al. (2001) | O’Hara et al. | Karakalpakstan, Uzbekistan | Children aged 7 to 11 | PM\(_{2.5}\) | Cross-sectional survey/multivariate regression model | Lung function | There was an inverse relationship between dust event and Lung function |

Other impacts

| Lee et al. (2019) | Lee et al. | Korean national | All ages/all gender | PM\(_{10}\) | Case-crossover/conditional logistic regression | Risk of suicide | Suicide risk, 13.1% \(4.5-22.4\) P = 0.002 |
| Soy et al. (2016) | Soy et al. | Mardin, Turkey | All gender/18 to 65 years | PM\(_{10}\) | Prospective study/pairs t-test | Quality of life(QoL) in patients with or without asthma | QoL, AR 2.5-fold higher SF-36, AR 1.9-fold higher |
| Islam et al. (2019) | Islam et al. | Saudi Arabia | All ages/all gender | – | Ecological/panel regression models | Road traffic accidents | \(P \leq 0.05\) |
| Mu et al. (2010) | Mu et al. | Choyr City, Mongolia | 44.2 ± 17.3/all gender | – | Cross-sectional/student’s t-test/multiple regression analysis | Health-related Quality of Life | Decreased HRQOL P < 0.05 |

(Continued)
| Reference | First Author and Year | Location | Population (Age, Gender) | Study Design/Methodology | Health Outcomes | Results |
|-----------|------------------------|----------|--------------------------|--------------------------|----------------|---------|
| Sing and symptom | | | | | | |
| Higashi et al. (2014) | Higashi et al. (2014) | Japan | Aged 23–84 years, all gender | Panel study/logistic regression with a generalized estimating equation | Health outcomes | Respiratory symptoms increased 4% Unaffected 48% |
| Watanabe et al. (2012) | Watanabe et al. (2012) | Japan | Between 23 and 84 | TSP Descriptive telephone survey/multivariate logistic regression analysis | Health outcomes | |
| Reference                      | First Author and Year | Study Location         | Population (Age, Gender) | PM Fraction | Study Design/Methodology                                      | Health Outcomes                                                                 | Results                                                                 |
|-------------------------------|-----------------------|------------------------|--------------------------|-------------|---------------------------------------------------------------|-------------------------------------------------------------------------------|--------------------------------------------------------------------------|
| Watanabe et al.              | Watanabe et al. (2015)| Western Japan          | Aged >18 years            | SPM         | Panel study/linear regression analysis                       | Respiratory symptoms in adult patients with asthma                             | All symptom 0.04 (0.03, 0.05)                                            |
| Park et al.                  | Park et al. (2005)    | Incheon, Korea         | Ages of 16 and 75 years/all gender | PM_{10}     | Prospective study/t-test/GAM with Poisson log-linear regression | Respiratory symptoms of asthmatics                                             | Nighttime symptoms RR 1.05 (0.99–1.17)                                    |
| O’Hara et al.                | O’Hara et al. (2001)  | Karakalpakstan, Uzbekistan | Children aged 7 to 11    | PM_{10}     | Descriptive studies/cross-sectional survey/multivariate regression model | Respiratory symptoms and lung function                                         | There is an apparent inverse relationship between total dust exposure and respiratory health |
| Watanabe et al.              | Watanabe et al. (2011)| Western Japan          | At least 18 years old     | SPM         | Cross-sectional telephone survey/multivariate logistic regression analysis | Worsening asthma                                                              | Aggravated lower respiratory tract symptoms in asthma patients            |
| Meo et al.                   | Meo et al. (2013)     | Riyadh, Saudi Arabia   | Age 28.6±3.14 years/all gender | –           | Descriptive studies / Chi square test                         | General health complaints                                                     | OR                                                                 |
|                              |                       |                        |                          |             |                                                               | Wheeze 4.18 (2.36–7.41)                                                        |                                                                            |
|                              |                       |                        |                          |             |                                                               | Cough 4.13 (2.28–7.46)                                                         |                                                                            |
|                              |                       |                        |                          |             |                                                               | Acute asthmatic attack 6.7 (4.09–10.99)                                        |                                                                            |
|                              |                       |                        |                          |             |                                                               | Psychological disturbances 3.72 (2.48–5.57)                                     |                                                                            |
|                              |                       |                        |                          |             |                                                               | Eye irritation/redness 7.89 (4.4–14.16)                                         |                                                                            |
|                              |                       |                        |                          |             |                                                               | Headache 4.17 (2.8–6.2)                                                        |                                                                            |
|                              |                       |                        |                          |             |                                                               | Body ache 1.24 (0.82–1.88)                                                     |                                                                            |
|                              |                       |                        |                          |             |                                                               | Sleep disturbance 4.16 (2.77–6.22)                                             |                                                                            |
|                              |                       |                        |                          |             |                                                               | Runny nose 31.9 (14.33–70.96)                                                  |                                                                            |

Abbreviations: ρ, Spearman correlation coefficients; AOD, aerosol optical depth; AMI, acute myocardial infarction; ACS, acute coronary syndrome; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; GAM, generalized additive model; IHD, ischemic heart disease; IR, increase risk; OR, odds ratio; PM, particulate matter; PM_{10}, particles less than 10 μm in aerodynamic diameter; PM_{2.5}, particles less than 2.5 μm in aerodynamic diameter; PM_{2.5–10}, particles with an aerodynamic diameter >2.5 μm and <10 μm; PTB, pulmonary tuberculosis; QoL, quality of life; RR, relative risk; SPM, suspended particulate matter; TSP, total suspended particulate.
Daily symptoms such as nasopharyngeal, skin, or ocular symptoms, and decreased pulmonary function (Table 1).

The current analysis indicated that the effects of dust storms on health can be divided into 2 general sections: short- and long-term effects. **Short-term effects** have been defined herein as human health problems that occurred during or immediately after a dust storm, and **long-term effects** are defined as human health problems that occurred after a long exposure to several periods of dust storms.

**Short-Term Health Effects**
The short-term effects included all-cause mortality, emergency dispatch or air medical retrieval service, hospitalization or admission, healthcare visits, daily symptoms, decreased pulmonary function, and other problems.

**Mortality**
Thirty-three articles from almost all regions discussed mortality due to dust storms by means of different health problems, such as increased total non-accidental deaths, increased cardiovascular deaths, mortality due to acute coronary syndrome (ACS), and respiratory mortality. Some studies reported, however, that the number of cases was not increased significantly for all-causes, respiratory, cardiovascular, or cerebrovascular mortality. Neophytou et al. in Nicosia reported that associations for respiratory mortality was −0.79 (−4.69, 3.28) on dust storm days. Lee et al. in Taipei found that dust storms have a protective effect on non-accidental deaths, respiratory deaths, and death in people >65 years of age.

**Emergency dispatch or air medical retrieval service**
Four articles discussed the emergency medical services required due to dust storm, focusing on different health problems. This review observed an increased relative risk of all medical emergency dispatches and a significant increase in cardiovascular dispatches, increased daily ambulance calls due to respiratory, cardiovascular, and all causes, and an increase in emergency
dispatches due to cardiovascular, respiratory, injury and all causes.\textsuperscript{90}

**Hospitalization or admission**

Sixty-two articles from almost all regions discussed hospitalization or admission due to dust storms by means of different health problems or diseases. The results indicated that in many studies, dust storms were associated with an increased risk of hospital admission due to cardiovascular, cerebrovascular, and respiratory diseases, among others.

**Cardiovascular disease (CVD) hospitalizations or admissions.** In relation to cardiovascular diseases and the effect of dust storms, 17 studies stated that dust storms can increase: (1) the risk of circulatory outpatients and inpatients\textsuperscript{91}; (2) odds ratio of admission and hospitalization due to congestive cardiac failure\textsuperscript{68} and acute coronary syndrome\textsuperscript{28}; (3) effects on cardiac diseases\textsuperscript{92}; (4) risk of CVD hospitalization or admission\textsuperscript{40,78,93-97}; (5) emergency admissions for CVD\textsuperscript{92}; (6) the impacts on acute myocardial infarction (AMI)\textsuperscript{98-100}; (7) emergency hospital admissions for ischemic heart diseases (IHD)\textsuperscript{101}; (8) hospital admissions for congestive heart failure (CHF)\textsuperscript{102}; and (9) inpatient hospitalization due to cardiac failure.\textsuperscript{86} However, some studies reported non-significant results, such as no association between dust storms and out-of-hospital cardiac arrests\textsuperscript{103} and no significant changes in admissions concerning cardiovascular syndromes.\textsuperscript{104} Also, some reported no significant association between increased dust particles and angina.\textsuperscript{90} Bennett et al.\textsuperscript{105} reported that the dust storms were not associated with an excess of CVD hospitalizations.

**Respiratory disease hospitalizations or admissions.** Regarding respiratory diseases related to dust storms, 35 studies stated that dust storms can increase the risk of respiratory outpatients\textsuperscript{11,40,43,51,57,78,92,93,96,104,106-114} cases of bronchial asthma,\textsuperscript{93} asthma-related hospitalizations or admissions,\textsuperscript{51,57,112-116} cases of aggravated asthma disease,\textsuperscript{117,118} daily pneumonia admissions,\textsuperscript{119,120} hospital admissions for chronic obstructive pulmonary disease (COPD),\textsuperscript{50,87,123-125} emergency hospital admissions for COPD,\textsuperscript{124} emergency admissions for respiratory diseases,\textsuperscript{92} admitted patients suffering from respiratory infection,\textsuperscript{100} and the prevalence of chronic bronchitis, cough, and rhinitis.\textsuperscript{125}

Surprisingly, several studies did not find any link between dust storms and negative health outcomes, such as no significant effect on asthma exacerbations in Riyadh,\textsuperscript{126} no significant change in the risk of emergency admission in dust events,\textsuperscript{127} and no association between sandstorms and risk of hospital admission for asthma or pneumonia patients.\textsuperscript{98} Moreover, some studies reported no statistically significant relationship between increased dust levels and pulmonary function, allergic disease, emergency admission, or drug use\textsuperscript{128}; no significant relationship between increased risk of chronic obstructive pulmonary disease, asthma, and angina and increased concentration of dust storms\textsuperscript{60,129}. And no excess risk of respiratory hospitalizations.\textsuperscript{105} Only two studies found a decrease in respiratory problems after dust storms, like a decreased risk of respiratory inpatients in Taklimakan Desert,\textsuperscript{91} and a lower rate of respiratory problems among children in areas with higher levels of dust deposition as reported by Wiggs et al.\textsuperscript{130}

**Cerebrovascular diseases hospitalizations or admissions.** Regarding the correlation between cerebrovascular diseases and dust storms, 6 studies stated that dust storms can increase the risk of cerebrovascular diseases,\textsuperscript{40,92} the incidence of athero-thrombotic brain infarction,\textsuperscript{131} stroke admission rates,\textsuperscript{132} hospital admissions for epilepsy problems, cerebral ischemic attacks, and various types of headaches,\textsuperscript{133} and daily intracerebral hemorrhagic (ICH) stroke admissions.\textsuperscript{134} Bell et al.,\textsuperscript{56} however, reported that sandstorms have no significant relationship with the risk of admission to cerebrovascular patients. Moreover, Yang et al.\textsuperscript{134} stated that there is no significant association between the risk of ischemic stroke and dust storms.

**Other diseases hospitalizations or admissions.** Aili et al.\textsuperscript{91} reported that the risk of digestion outpatients and inpatients, gynecology outpatients, pediatrics outpatients and inpatients, and ENT outpatients and inpatients was increased during dust storms. Chan et al.\textsuperscript{135} also stated that dust storms were significantly associated with diabetes admissions for females. Furthermore, Ko et al.\textsuperscript{137} stated that dust storms can increase the risk of conjunctivitis.

**Healthcare visits**

Nineteen articles studied the daily number of healthcare visits due to dust storms for different health problems. Except for 1 article, all others reported that dust storms are associated with an increased daily number of healthcare visits due to asthma-related health problems\textsuperscript{137-141} cardiac, respiratory, and stroke diagnoses,\textsuperscript{142} emergency healthcare visits for IHD, CVD, and COPD,\textsuperscript{143} conjunctivitis clinic visits,\textsuperscript{144,145} children clinic visits for respiratory problems,\textsuperscript{139,146} healthcare visits for respiratory diseases,\textsuperscript{52,139,146,147} healthcare visits for all causes, circulatory, and respiratory diseases,\textsuperscript{148} and for cardiovascular and respiratory problems.\textsuperscript{149,150} Lorentzou et al.\textsuperscript{122} also reported a large increase in emergency visits related to dyspnea during dust storms; however, no clinically significant increase was observed in the total number of emergency visits.

**Daily symptoms**

Twenty articles studied the daily symptoms resulting from dust storms. In 2 studies, Higashi et al.\textsuperscript{151,152} showed the effects of Kosa on cough. Otani et al.\textsuperscript{153} found that the scores for symptoms (nasopharyngeal, ocular, respiratory, and skin) were significantly higher when related to dust storms. Onishi et al.\textsuperscript{154}
reported that all symptoms (nasal, ocular, respiratory, throat, and skin) increased after exposure to dust storms. Mu et al.\textsuperscript{39} also reported that an increased risk of eye lacrimation occurrence is associated with dust events. Majbauddin et al.\textsuperscript{155} reported a positive correlation between the increased concentration of dust storms and ocular, nasal, and skin symptoms. Similarly Meo et al.\textsuperscript{156} observed that sandstorms can increase complaints of sleep and psychological disturbances as well as other problems like eye irritation, cough, wheeze, headache, and runny nose.

**Pulmonary function**

Nine articles discussed pulmonary function in relation to dust storms, and the evidence is conflicting. Kurai et al.,\textsuperscript{157} Watanabe et al.,\textsuperscript{158,159} Yoo et al.\textsuperscript{160} and Watanabe et al.\textsuperscript{161} all found that dust storms have a significant, negative effect on pulmonary function. Other studies, including Hong et al.,\textsuperscript{162} Watanabe et al.\textsuperscript{159} and Park et al.\textsuperscript{163} found no significant relationship between pulmonary function and dust storms. Kanatani et al. found that dust storms can increase the risk of allergic symptoms in pregnant women.\textsuperscript{164} Yoo et al.,\textsuperscript{160} reported a significant increase in respiratory symptoms during dust storms, and Watanabe et al.\textsuperscript{159} reported that sand and dust storms are significantly associated with respiratory symptoms. Moreover, Park et al.\textsuperscript{163} reported a relationship between nighttime symptoms and particular matter levels during dust storms. Watanabe et al.\textsuperscript{165} also stated that dust storms worsen respiratory symptoms in asthmatic patients, but some studies like O’Hara et al.\textsuperscript{166} reported that pulmonary function was better in children who were more exposed to dust storms than in those with low exposure to dust.

**Other impacts**

Some articles explored the relationship of dust storms with road traffic accidents, risk of suicide, placental abruption, and health-related quality of life. Islam et al.\textsuperscript{167} found that sandstorms and the number of vehicles were significantly responsible for road traffic accidents. Soy et al.\textsuperscript{108} reported that dust storms can have adverse effects on the quality of life of patients with asthma and allergies. Mu et al.\textsuperscript{117} reported that dust storms can decrease health-related quality of life in everyone exposed to them. Lee et al.\textsuperscript{168} reported that exposure to dust storms was associated with an increased risk of suicide (13.1%; \( p = 0.002 \)).

**Long-Term Health Effects**

Six articles discussed the long-term adverse health effects caused by dust storms by means of different outcomes, like reduced birth weight, baby’s birth weight <2.5 Kg, gestation/ gestational age >37 weeks and premature birth,\textsuperscript{32} and decreased cognitive function in children.\textsuperscript{33} Preterm births\textsuperscript{34} were correlated with Valley fever incidences\textsuperscript{36} and increased spring measles incidence.\textsuperscript{44} Only one article was observed to indicate no significant effect of desert dust storms on pregnancy consequences.\textsuperscript{169}

**Discussion**

In this study, the majority of valid scientific databases were searched to find articles and studies related to the health effects of dust storms. Other similar studies have used fewer scientific databases in their search. The final number of articles included in this study is higher than that in all previous studies.\textsuperscript{24,26} The current results showed that the model most used to evaluate the health effects of dust storms was the GAM method. In this regards, Ramsay 2003 stated, “Such methods eliminate the need to specify a parametric form for secular trends and allow a greater degree of robustness against model misspecification.”\textsuperscript{170} The results of the current study also showed that most dust storm studies have been carried out in Japan, Taiwan, and South Korea, which may be due to the large number of dust storms occurring in Northeast Asia. This area is exposed to yellow dust storms caused by strong winds on the Loos Plateau and the Gobi and Talkmanistan Deserts, and as yellow dust storms became so prevalent in that area within the last two decades, researchers in the area have studied their health effects.\textsuperscript{152,171}

The review results showed that most studies around the world confirm the adverse effects of dust storms on health. The relevant health problems were categorized into long-term and short-term impacts. Few studies were found that focused on the long-term impacts of dust storms on human and public health; however, those studies found showed that dust storms may increase the risks for problems in pregnancy and childbirth, children’s cognitive problems, and infectious diseases. In line with the risks of birth as well as cognitive problems in children, animal studies have shown that the fetal brain is easily exposed to air pollutants, because in the human fetus, the blood-brain barrier has not yet developed; therefore, the fetal brain is exposed to pollutants and is sensitive to blood changes caused by them.\textsuperscript{1-3} Furthermore, new research on humans has shown that environmental pollutants can possibly create inflammation, oxidative stress, and vascular damage to the fetal brain after passing through the placenta.\textsuperscript{4-7} Researchers have studied the effects of PM from dust storms on maternal health during pregnancy and birth problems, and they refer to variations in maternal host-defense mechanisms, maternal-placental exchanges, oxidative pathways, and endocrine dysfunction as possible causes of these problems.\textsuperscript{8} Ultimately, the evidence from infectious diseases shows that pathogenic microorganisms are abundant in dust storms,\textsuperscript{9} and dust storms can spread these microorganisms over a large area. Therefore, it can be argued that microorganisms that are suspended or attached to dust particles can be transferred from one part to another and may induce infectious diseases at various destinations by dust storms.\textsuperscript{10,11} More studies have been conducted on the short-term impacts of dust storms. The majority of these studies indicate the effects of dust storms on important body systems,
including the cardiovascular, respiratory and cerebral systems, which lead to the increased incidence of clinical symptoms and severity of symptoms; increased emergency visits, ambulance dispatches, and hospitalizations or admissions; decreased lung capacity; and eventually death.

Most studies show that dust storms increase the risk of cardiovascular problems, the number of cardiovascular emergency medical dispatches, cardiovascular visits, the number of cardiovascular symptoms among patients referring to the hospital, cardiovascular admissions or hospitalizations, and deaths due to cardiovascular disease. Although the exact mechanism for the effects of dust storms on heart problems has not yet been determined, studies show that fine particles in dust storms can enter lung tissue and the bloodstream through chemical interactions, causing a thrombolytic and inflammatory process and the secretion of cytokines in the body. Moreover, the toxicity of some of these substances in the body reduces the contractibility of the heart, increases vasoconstriction, and increases blood pressure. Therefore, the above cases may confirm the effects of dust storms on cardiovascular health.

The results of the current study showed that according to most articles, the risk of death following respiratory problems; the risk of admission and hospitalization due to respiratory disorders like pneumonia, asthma, and chronic obstructive pulmonary disease and other respiratory problems; respiratory symptoms; and healthcare visits associated with dust storms have increased. Other results showed that dust storms reduce lung capacity and function. The results of studies have shown that 1 mechanism of dust storms is that small particulates in dust storms are likely to trigger an innate immune response by T-lymphocytes in the body and respiratory system, which can cause chronic inflammation and advanced COPD. PM can also play a significant role in respiratory oxidative stress, increase pulmonary inflammation, increase atopic responses and Immunoglobulin E production in respiratory problems (especially asthma), and exacerbate symptoms. Another mechanism that may cause respiratory illnesses following a dust storm is the presence of pathogens such as microorganisms and fungi as well as some minerals such as silica in some of these storms. These particles enter the airway after dust storms and exacerbate the disease or cause respiratory problems in people at risk. For example, neutrophilic pulmonary inflammation may be caused by bacterial and fungal debris in dust particles to which individuals are exposed. Some of this debris includes lipopolysaccharide (LPS), a cell wall glycolipid of gram-negative bacteria, and β-glucan, which is the most important constituent of the fungal wall. Both of them are clearly observed in dust storms along with dust particles. Although the precise mechanisms for pneumonia are yet to be found, some studies have suggested that high amounts of particles in dust storms can cause oxidative stress, induce inflammation, increase blood clotting, disrupt defense cells, and cause immune system fluctuations, ultimately inducing alveolar inflammation and exacerbating lung disease.

In 2009, Calderon Garosia stated that pollutants in dust storms can cause problems such as cardiovascular, respiratory, liver, and skin toxicity through systemic inflammation and may induce a pre-inflammatory systemic response in cytokines, which may disrupt the HPA axis and ultimately cause mood swings and psychological problems, including suicidal thoughts. In addition, chemical components found in dust storms can enter the brain through the mucosa and olfactory system. After entering the nervous system, they may accumulate in the anterior cortex of the brain and cause problems in emotional regulation and impulse control. Some researchers also suggest that some mechanisms are associated with placental abruption due to dust storms, such as microbiological and chemical substances in dust storms that induce an inflammatory response in the body. Inflammation and ischemia increase the risk of decidual bleeding, followed by hematoma formation and placental abruption. There is also some speculation that as lipopolysaccharide has been found in Asian dust storms, the activity of this endotoxin in the body may lead to premature birth due to chorioamnionitis, which is also associated with placental abruption.

The current review shows that some studies have also linked dust storms with some other health problems, such as increased road accidents, increased suicide risk, increased premature placental abruption, ocular problems, and reduced quality of life. These issues could be further studied in areas prone to dust storms. Islam stated that the reduced field of vision, the lack of dust storm warning systems, and traffic due to dust and sand storms can be considered as reasons for the recent increase in number of road accidents. Dust particulates in these storms can also cause acute ocular problems such as tears and conjunctivitis in people due to their inflammatory effects. In terms of the quality of life, Mu stated that an increase in health problems and clinical symptoms that are associated with allergens and ocular problems such as conjunctivitis dust storms reduce the quality of life.

Despite all the significant effects of dust storms on health, this review found some studies that presented no significant association between dust storms and health problems including all-cause and respiratory mortality, cardiovascular, and respiratory problems. Moreover, some studies reported that dust storms may have a protective effect against non-accidental and respiratory death and other pulmonary problems.

However, O’Hara stated that although the lack of matching of exposed and non-exposed groups in nutritional, economic, and social problems may play a role in the insignificance of the effects of dust storms on health, the chemical and physical nature of the particles in dust storms are of more importance than their total amounts. Differences in the chemical and physical nature of particulate matters may cause different health outcomes in varying regions. Another reason for the
difference may be the use of rapid early warning systems in some countries. Lee justified the protective effects of dust storms on death, stating that in Taipei, a complex rapid early warning system is used for dust storms, and the use of this system may produce protective effects of dust storms on mortality.55 Finally, almost all of the reviewed articles reported on a group of diseases or deaths that were studied, while dust storms may not affect all diseases and deaths.52 This may be another reason for these differing results.

Conclusion
This systematic review presents an accurate and comprehensive study of all aspects of human health in relation to dust storms. For the first time in the world, this in-depth and unique study was conducted to summarize the short-term and long-term effects of dust storms. To date, this amount of reliable data on this issue has never been investigated. As the results showed, despite the short-term effects dust storms have on human health (including adverse effects on the respiratory, skin, ocular, cardiovascular, and cerebral systems as well as increased mortality and morbidity) that may occur immediately after each dust storm, the frequency of dust storms in an area is also an important factor. In addition to exacerbating short-term health effects, they may also cause long-term health effects, which may include health problems for pregnant mothers, fetuses and infants, in the cognitive function of children, and increases in some infectious diseases. Therefore, as climate change and drought have caused this phenomenon to endanger the lives of many people around the world, and as the health and well-being of people is a main priority in any country, it is recommended that more studies be conducted in countries exposed to dust storms to examine the health effects of these storms in order to better understand the mechanisms through which dust storms impact human and public health and to develop a better strategy for preparing for, preventing, and mitigating the destructive effects of these storms.

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Author Contributions
“HA and AOT designed the study; HA collected the data; HA and AOT analyzed and interpreted the data. HA, AOT, A Ardalan, MA, MY, CS and A Asgary prepared the manuscript. All authors contributed to the drafting and final review of the manuscript. The author (s) read and approved the final manuscript.”

Ethical Approval
Current study was approved by the Ethics Committee of Tehran University of Medical Sciences (TUMS) Ethics Code: IR.TUMS.SPH.REC.1399.004, and also all methods were performed in accordance with the relevant guidelines and regulations.

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REFERENCES
1. Shao Y, Wyrwoll K-H, Chappell A, et al. Dust cycle: an emerging core theme in Earth system science. *Aust J Environ Sci*. 2011;17(4):181-204.
2. Vodonos A, Friger M, Kataria I, et al. Individual effect modifiers of dust exposure effect on cardiovascular morbidity. *Plos One*. 2015;10(9):e0137714.
3. Crooks JL, Cascio WE, Percy MS, Reyes J, Neas LM, Hilborn ED. The association between dust storms and daily non-accidental mortality in the United States, 1993–2005. *Environ Health Perspect*. 2016;124(10):1735-1743.
4. Almeida-Silva M, Almeida SM, Freitas M, Pio C, Nunes T, Cardoso J. Impact of Saharan dust transport on Cape Verde atmospheric element particles. *J Trop Med Environ Health Part A*. 2013;76(4-5):240-251.
5. Ardon-Dryer K, Mock C, Reyes J, Lahav G. The effect of dust storm particles on single human lung cancer cells. *Environ Res*. 2020;181:108891.
6. Middleton N, Tozer P, Tozer B. Sand and dust storms: underrated natural hazards. *Disasters*. 2019;43(2):390-409.
7. Krueger BJ, Grassian VH, Cowin JP, Laskin A. Heterogeneous chemistry of individual mineral dust particles from different dust source regions: the importance of mineral mineralogy. *Atmos Environ*. 2006;38(36):6253-6261.
8. Goudie AS, Middleton NJ. Desert Dust in the Global System. Springer Science & Business Media; 2006.
9. Schweitzer MD, Caldzadilla AS, Salamo O, et al. Lung health in era of climate change and dust storms. *Environ Res*. 2018;163:36–42.
10. Fairlie TD, Jacob DJ, Park RJ. The impact of transpacific transport of mineral dust in the United States. *Atmos Environ*. 2007;41(6):1251-1266.
11. Grimeski SE, Staniswalis JG, Bielanska P, Peng Y, Gill TE. Hospital admissions for asthma and acute bronchitis in El Paso, Texas: do age, sex, and insurance status modify the effects of dust and low wind events? *Environ Res*. 2011;111(8):1148-1155.
12. Johnston F, Hanigan I, Henderson S, Morgan G, Bowman D. Extreme air pollution events from bushfires and dust storms and their association with mortality in Sydney, Australia 1994–2007. *Environ Res*. 2011;111(6):811-816.
13. WHO. Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulphur dioxide. Global update 2005. Summary of Risk Assessment. 2006.
14. Song Z, Wang J, Wang S. Quantitative classification of northeast Asian dust events. *J Geophys Res Atmos*. 2007;112(D4):D060748.
15. Hoffmann C, Funk R, Wieland R, Li Y, Sommer M. Effects of grazing and topography on dust flux and deposition in the Xilinggele grassland, Inner Mongolia. *J Arid Environ*. 2008;72(5):792-807.
16. Hamidi M, Kavianpour MR, Shao Y. Synoptic analysis of dust storms in the Middle East. *Asia-Pac J Atmos Sci*. 2013;49(3):279-286.
17. Shepherd G, Terradellas E, Baklanov A, et al. Global assessment of sand and dust storms; 2016. https://repositorio.aemet.es/handle/20.500.11765/4495
18. UNCCD. Sand and dust storms: United Nations Convention to Combat Desertification; 2020. https://www.unccd.int/actions/sand-and-dust-storms
19. Modarres R. Regional maximum wind speed frequency analysis for the arid and semi-arid regions of Iran. *J Arid Environ*. 2008;72(7):1329-1342.
20. Akhlaq M, Sheltami TR, Moufah HT. A review of techniques and technologies for sand and dust storm detection. *Rev Environ Sci Bio/Technol*. 2012;11(3):305-322.
21. Hahnenberger M, Nicol K. Meteorological characteristics of dust storm events in the eastern Great Basin of Utah, USA. *Atmos Environ*. 2012;60:601-612.
22. Duie RA. Sources, distributions, and fluxes of mineral aerosols and their relationship to climate. *Aerol Geoing of Clime*. 1995;6:43-72.
23. Jiang D, Liu Z, Cao C, Kou Z, Wang R. Desertification and Ecological Restoration of Keerqin Sandy Land China Environmental Science Press; 2003.
24. Goudie AS. Desert dust and human health disorders. *Environ Int*. 2014;63:101-113.
25. Liu R-T, Huza MA. Filtration and indoor air quality: a practical approach. *ASHRAE J*. 1995;37(2):24-31.
26. Zhang X, Zhao L, Tong DQ, Wu G, Dan M, Teng B. A systematic review of global desert dust and associated human health effects. *Atmosphere*. 2016;7(12):158.
27. Hsieh N-H, Liao C-M. Assessing exposure risk for dust storm events—associated lung function decrement in asthmatics and implications for control. Atmos Environ. 2013;68:256-264.
28. Jaafari J, Naddaf K, Yunesian M, et al. The acute effects of short term exposure to particulate matter from natural and anthropogenic sources on inflammation and coagulation markers in healthy young adults. Sci Total Environ. 2020;735:139417.
29. Jaafari J, Naddaf K, Yunesian M, et al. Associations between short term exposure to ambient particulate matter from dust storm and anthropogenic sources and inflammatory biomarkers in healthy young adults. Sci Total Environ. 2020;760:144503.
30. Agier L, Derouaux A, Martiny N, Yaka P, Djibio A, Broutin H. Seasonality of meningitis in Africa and climate forcing: aerosols stand out. JRC Sci Interface. 2013;10(79):20120814.
31. Panikkath R, Jumper CA, Mulkey Z. Multilobar lung infiltrates after exposure to dust storm: the Habbob Lung Syndrome. Am J Med. 2013;126(2):e5-e7.
32. Abtindag DT, Baek D, Mocan N. Chinese yellow dust and Korean infant health. Soc Sci Med. 2017;186:78-86.
33. Li Z, Chen L, Li M, Cohen J. Prenatal exposure to sand and dust storms and childhood's cognitive function in China: a quasi-experimental study. Lancet Planet Health. 2018;2(5):214-222.
34. Vieil JM, Mallet Y, Raghounandam C, et al. Impact of Saharan dust episodes on preterm births in Guadeloupe (French West Indies). Occup Environ Med. 2019;76(6):334-340.
35. Mu H, Battsetseg B, Ito TY, Otani S, Onishi K, Sajani A. Desert dust outbreaks and respiratory morbidity in Athens, Greece. J Toxicol Environ. 2012;68(17-18):1457-1464.
36. Aghababaeian H, Dastoorpoor M, Ghasemi A, Kiarsi M, Khanjani N, Ahvazi A. Air pollution and respiratory tract symptoms in patients with asthma over 4 years. Tuberk Respir Dis. 2015;78(4):326-335.
37. Wang Y, Wang R, Ming J, et al. Effect of dust storm events on weekly clinic visits related to pulmonary tuberculosis disease in Minjin, China. Atmos Environ. 2019;208:205-211.
38. Kashima S, Yorifuji T, Tsuda T, Eboshida A. Asian dust and daily all-cause or cardiovascular mortality in seven metropolitan cities of Korea. Environ Health. 2014;13:81.
39. Diaz J, Tobias A, Linares C. Saharan dust and association between particulate matter and case-specific mortality: a case-crossover analysis in Madrid (Spain). Environ Health. 2012;11:11.
40. Hwang SS, Cho SH, Kwon HJ. The effect of Asian dust events on mortality in the spring of 2002, Seoul, Korea. Epidemiology. 2004;15(4):510-517.
41. Jaafari J, Naddafi K, Yunesian M, et al. Long-range transported Asian dust on mortality in five cities across South Korea and Japan. Epidemiology. 2019;11(4):264-271.
42. Samoli E, Kougou E, Kassomenos P, Analitis A, Katsouyanni K. Does the presence of desert dust modify the effect of PM10 on mortality in Athens, Greece? Sci Total Environ. 2011;409(11):2049-2054.
43. Lee H, Honda Y, Lim YH, Guo YL, Hashizume M, Kim H. Effect of Asian dust storms on mortality in three Asian cities. Atmos Environ. 2014;89:309-317.
44. Samoli E, Kougou E, Kassomenos P, Analitis A, Katsouyanni K. Does the presence of desert dust modify the effect of PM10 on mortality in Athens, Greece? Sci Total Environ. 2011;409(11):2049-2054.
45. Lee H, Honda Y, Lim YH, Guo YL, Hashizume M, Kim H. Effect of Asian dust storms on mortality in three Asian cities. Atmos Environ. 2014;89:309-317.
46. Bell ML, Levy JK, Lin Z. The effect of sandstorms and air pollution on cause-specific hospital admissions in Taipei, Taiwan. Occup Environ Med. 2008;65(2):104-111.
47. Ueda K, Nitta H, Odaizuma H. The effects of weather, air pollutants, and Asian dust on hospitalization for asthma in Fukuoka. Environ Health Prev Med. 2010;15(6):350-357.
48. Pin MK, Kim CW, Yun YJ, et al. Effect of yellow sand on respiratory symptoms and diurnal variation of peak expiratory flow in patients with bronchial asthma. J Asthma Allergy Clin Immunol. 2003;1(6):1179-1186.
49. Dong T, Dung T, Lee BK, Huh YS, Cho SW, editors. An analysis on the effects of Asian dust event on human health in large cities of Korea based on the number of patients. 2007 International Forum on Strategic Technology, IFOST, 2007.
50. Goto K, Nomor JC, Kurihashi R, et al. Relationship between influx of yellow dust and asthma mortality using satellite data. Sci Total Environ. 2010;5(24):4044-4052.
51. Ueda K, Shimizu A, Nitta H, Inoue K. Long-range transported Asian dust and emergency ambulance dispatches. Inhaled Toxicol. 2012;24(2):857-866.
52. Park J, Lim MN, Hong Y, Kim WJ. The influence of Asian dust, haze, mist, and fog on hospital visits for airway diseases. Tuberk Respir Dis. 2015;78(4):326-335.
53. Wang Y, Wang R, Ming J, et al. Effect of dust storm events on weekly clinic visits related to pulmonary tuberculosis disease in Minjin, China. Atmos Environ. 2019;208:205-211.
54. Yu HZ, Chien LC, Yang CH. Asian dust storm elevates children's respiratory health risks: a spatiotemporal analysis of children's clinic visits across Taipei (Taiwan). PLoS One. 2017;12(7):e014317.
107. Geravandi S, Sicard P, Khaniabadi YO, et al. A comparative study of hospital admissions during desert dust storms. Int J Environ Res Public Health. 2017;14(22):18151-18159.

108. Lai LW, Cheng WL. The impact of air quality on respiratory admissions during desert dust storms in Hong Kong. Atmos Environ. 2017;169:73-82.

109. Reyes M, Diaz J, Tobais A, Montero JC, Linares C. Impact of Saharan dust particles on hospital admissions in Madrid (Spain). Int J Environ Res Public Health. 2014;11(4):1243-1257.

110. Niu B, Bogan M, Zengin S, et al. Effects of dust storms and climatological factors on mortality and morbidity of cardiovascular diseases admitted to ED. Emerg Med Int. 2018:2018:3758506.

111. Kwon HJ, Cho SH, Chun Y, Lagarde F, Pershagen G. Effects of the Asian dust events on daily mortality and number of admissions for patients with respiratory diseases in spring in Lanzhou, China. Sci Total Environ. 2012;428:9-11.

112. Gyan K, Henry W, Lacaille S, et al. African dust clouds are associated with increased paediatric asthma accident and emergency admissions on the Caribbean island of Trinidad. Int J Biometeorol. 2005;49(6):371-376.

113. Fang CH, Chen CS, Lin CL. The threat of Asian dust storms on asthma patients: a population-based study in Taiwan. Glob Public Health. 2014;9(9):1040-1052.

114. Kanatani KT, Ito I, Al-Delaimy WK, Adachi Y, Mathews WC, Ramsdell JW. Desert dust exposure is associated with increased risk of asthma hospitalization in children. Ann J Respir Crit Care Med. 2010;182(12):1475-1481.

115. Yang CY, Tsai SS, Chang CC, Ho SC. Effects of Asian dust storm events on daily admissions for asthma in Taipei, Taiwan. Int J Environ Res Public Health. 2015;12(4):481-489.

116. Lee JW, Lee KK. Effects of Asian dust events on daily asthma patients in Seoul, Korea. Meteorol Appl. 2014;21(2):202-209.

117. Rutherford S, Clark E, McIntosh G, Simpson R, Mitchell C. Characteristics of rural dust events shown to impact on asthma severity in Brisbane, Australia. Int J Biometeorol. 1999;42(2):71-75.

118. Cheng MF, Ho SC, Chia HF, Wu TN, Chen PS, Yang CY. Consequences of exposure to Asian dust storms on daily pneumonia hospital admissions in Taiwan. Int J Environ Res Public Health. 2008;7(19):1295-1299.

119. Kang JH, Keller JJ, Chen CS, Lin HC. Asian dust storm events are associated with acute increase in pneumonia hospitalization. Ann Epidemiol. 2012;22(4):257-263.

120. Chiou HF, Tiao MM, Ho SC, Kuo HW, Wu TN, Yang CY. Effects of Asian dust storm events on hospital admissions for chronic obstructive pulmonary disease in Taipei, Taiwan. Int J Environ Res Public Health. 2014;11(10):4811-4819.

121. Lorenzoni C, Kousarzadeh G, Kosyrskiy GV, et al. Extreme desert dust storms and COPD morbidity on the island of Crete. Int J Chron Obstruct Pulmon Dis. 2019;14:1763-1768.

122. Vodonos A, Friger M, Katra I, et al. The impact of desert dust exposures on hospitalizations due to exacerbation of chronic obstructive pulmonary disease. Air Q. 2014;60(4):433-439.

123. Tam WW, Wong TW, Wong AH, Hui DS. Effect of dust storm events on daily emergency admissions for respiratory diseases. Respir Med. 2012;106(1):144-148.

124. Wang JY, Li S, Wang SG, Shang KZ. Effects of long-term dust exposure on human respiratory system health in Minqin County, China. Arch Occup Environ Health. 2015;70(4):225-231.

125. Alangari AA, Riaz M, Mahjour MO, Malshe N, Al-Tamimi S, Al-Mudaish A. The effect of sand storms on acute asthma in Riyadh, Saudi Arabia. Ann Thorac Med. 2015;10(1):29-31.

126. Barnett AG, Fraser JV, Münk L. The effects of the 2009 dust storm on emergency admissions to a hospital in Brisbane, Australia. Int J Biometeorol. 2012;56(4):719-726.

127. Menendez I, Derbyshire E, Carrillo T, et al. Saharan dust and the impact on adult and elderly allergic patients: the effect of threshold values in the northern sector of Gran Canaria, Spain. Int J Environ Res Public Health. 2017;14(27):244:164-166.

128. Prospero JM, Blades E, Naidu R, Mathison G, Tran H, Lavoie MC. Relationships between African dust carried in the Atlantic trade winds and surges in pediatric asthma attendances in the Caribbean. Int J Biometeorol. 2008;52(8):823-832.

129. Wiggs GF, O’bara SL, Wergedt J, Van Der Meer J, Small I, Hubbard R. The dynamics and characteristics of aeolian dust in dryland Central Asia: possible impacts on human exposure and respiratory health in the Aral Sea basin. Geogr J. 2003;169(2):142-157.

130. Kaynak M, Ueda K, Aso T, Iwata K, Harada T, Takano A. Desert dust exposure is associated with increased risk of asthma hospitalization: a case-crossover study. Int J Biometeorol. 2012;56(13):3059-3070.

131. Kan K, Liu TC, Keller J, Lin HC. Asian dust storm events are associated with increased hospital admissions due to exacerbation of chronic obstructive pulmonary disease. Int J Environ Res Public Health. 2014;11(10):4292-4299.

132. Radmanesh E, Maleki H, Goudarzi G, et al. Cerebral ischemic attack, epilepsy and hospital admitted patients with types of headaches attributed to air pollution and dust storms. Int J Occup Environ Health. 2014;20(6):628-632.

133. Brahmachari P, Majumdar A, Majumdar A. Environmental impacts on human health during a Saharan dust episode at Crete Island, Greece. Atmos Environ. 2012;366(2-3):918-925.

134. Ebenstein A, Frank E, Reingewertz Y. Particulate matter concentrations, short-term changes in air pollution and dust storms. Environ Sci Pollut Res Int. 2016;23(21):13227-13231.
135. Ko R, Hayashi M, Hayashi H, et al. Correlation between acute conjunctivitis and Asian dust on ocular surfaces. J Toxicol Environ Health A. 2016;79(8):367-375.

136. Akpinar-Eli M, Martin FE, Beht JG, Diaz R. Saharan dust, climate variability, and asthma in Grenada, the Caribbean. Int J Biometeorol. 2015;61(5):959-967.

137. Cadela G, Tournes R, Molinie J. Short-term effects of the particulate pollutants contained in Saharan dust on the visits of children to the emergency department due to asthmatic conditions in Guadeloupe (French Archipelago of the Caribbean). PLoS One. 2014;9(3):e91136.

138. Nakamura T, Hashimoto M, Ueda K, et al. Asian dust and pediatric emergency department visits due to bronchial asthma and respiratory diseases in Nagasaki, Japan. J Epidemiol. 2016;26(11):593-601.

139. Park YS, Kim JH, Jang HJ, Tae YH, Lim DH. The effect of Asian dust on asthma by socioeconomic status using national health insurance claims data in Korea. Inhal Toxicol. 2016;28(1):1-6.

140. Merrifield A, Schindeler S, Jalaludin B, Smith W. Health effects of the September 2009 dust storm in Sydney, Australia: did emergency department visits and hospital admissions increase? Environ Health. 2015;12:32.

141. Carlsen HK, Gislason T, Forsberg B, et al. Emergency hospital visits in association with volcanic ash, dust storms and other sources of ambient particles: a time-series study in Reykjavik, Iceland. Int J Environ Res Public Health. 2015;12(4):4047-4059.

142. Chan CC, Chuang KJ, Chen WJ, Chang WT, Lee CT, Peng CM. Increasing cardiorespiratory emergency visits by long-range transported Asian dust storms in Taiwan. Environ Res. 2008;106(3):393-400.

143. Chien LC, Lien YJ, Yang CH, Yu HL. Acute increase of children's conjunctivitis visits by Asian dust storms exposure - a spatiotemporal study in Taiwan. Taiwan. PLoS One. 2014;9(10):e109175.

144. Yang CY. Effects of Asian dust storm events on daily clinical visits for conjunctivitis in Taipei, Taiwan. J Toxicol Environ Health A. 2006;69(18):1673-1680.

145. Chien LC, Yang CH, Yu HL. Estimated effects of Asian dust storms on spatiotemporal distributions of clinical visits for respiratory diseases in Taipei children (Taiwan). Environ Health Perspect. 2012;120(8):1215-1220.

146. Hefflin BJ, Schindeler S, Jalaludin B, Smith W. Surveillance for dust storms and hospital admissions increase? Environ Health. 2015;12:32.

147. Lin YK, Chen CF, Yeh HC, Wang YC. Emergency room visits associated with particulate matter concentration and Asian dust storms in metropolitan Taipei. J Expo Sci Environ Epidemiol. 2016;26(2):189-196.

148. Liu YK, Chen CF, Yeh HC, Wang YC. Emergency room visits associated with particulate matter concentration and Asian dust storms in metropolitan Taipei. J Expo Sci Environ Epidemiol. 2016;26(2):189-196.

149. Liu ST, Liao CY, Kuo CY, Kuo HW. The effects of PM2.5 from Asian dust storms on emergency room visits for cardiovascular and respiratory diseases. Int J Environ Res Public Health. 2017;14(4):428.

150. Yang ZH, Zhang YX, Zhang QX, Zhang J, Lu B, Meng ZQ. Association of PM10-derived dust events with daily outpatient number for cardiopulmonary disease in China. Environ Sci Technol. 2016;50(14):7792-7798.

151. Yang ZH, Zhang YX, Zhang QX, Zhang J, Lu B, Meng ZQ. Association of PM10-derived dust events with daily outpatient number for cardiopulmonary disease in China. Environ Sci Technol. 2016;50(14):7792-7798.

152. Hong Y-C, Pan X-C, Kim S-Y, et al. Asian dust storm and pulmonary function of school children in Seoul. Stud Environment. 2010;408(4):754-759.

153. Park JW, Lim YH, Kryung SY, et al. Effects of ambient particulate matter on peak expiratory flow rates and respiratory symptoms of asthmatics during Asian dust periods in Korea. Respir Res. 2005;10(4):470-476.

154. Kanatani KT, Hamazaki K, Inadera H, et al. Effect of desert dust exposure on allergic symptoms a natural experiment in Japan. Ann Allergy Asthma Immunol. 2010;104(4):413-421.

155. Watanabe M, Yamaoka A, Burioka N, et al. Correlation between Asian dust storms and worsening asthma in Western Japan. Allergol Int. 2011;60(5):270-275.

156. O'Hara SL, Wiggs GFS, Wegerdt J, et al. Dust exposure and respiratory health amongst children in the environmental disaster zone of Karakalpakstan, Central Asia: preliminary findings of the ASARD project. Environ Health Risk. 2001;57:1-82.

157. Islam MM, Alharthi M, Alam MM. The impacts of climate change on road traffic accidents in Saudi Arabia. Climate. 2019;7(9):103.

158. Soy FK, Yaisci H, Kolduk K, et al. The effects of desert dust storms on quality of life of allergic patients with or without asthma. Kulak Burun Bogaz. Htri Derg. 2016;6(1):19-27.

159. Mu H, Bartsch O, Ito TY, Otani S, Onishi K, Kurozawa Y. Effects of Asian dust storm on health-related quality of life: a survey immediately after an Asian dust storm event in Mongolia. Int J Health Sci. 2010;3(2):87-92.

160. Lee H, Jung J, Mun W, et al. Association between dust storm occurrence and risk of suicide: case-crossover analysis of the Korean national death database. Environ Int. 2019;133(Pt A):105146.

161. Badhwar P, Basagana X, Figueras F, et al. Saharan dust episodes and pregnancy. J Environ Monit. 2013;15(11):3222-3228.

162. Hashizume M, Ueda K, Nishiwaki Y, Michikawa T, Onozuka D. Health effects of Asian dust events: a review of the literature. Jpn J Hyg. 2010;65(3):413-421.