Global Health Impacts of Dust Storms: A Systematic Review

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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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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 aluminum[6,7] 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 days[1-5] 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 PM_{10} (particles with an aerodynamic diameter <10 μm) and $PM_{2.5}$ (particles with an aerodynamic diameter <2.5 μm) particles are often higher than the normal thresholds recommended by the World Health Organization ($PM_{2.5}$: 10 μg/m^3 annual mean, 25 μg/m^3 24-hour mean. PM_{10}: 20 μg/m^3 annual mean, 50 μg/m^3 24-hour mean).[8,13] It can also exceed 6000 μg/m^3 in seriously strong dust storms.[14] According to the Huffman Classification of dust PM_{10} 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 years.[16,17,19] Researchers have demonstrated how dust storms affect various aspects of human life.[19] The particles in dust storms affect weather conditions, agricultural production, human health, and the ecosystem.[20,21] Evidence suggests that mineral aerosols affect cloud formation and precipitation and can reduce the acidity of precipitation.[22] Moreover, a high density and diversity of bacteria and plant pollens have been observed during dust storms.[23] In addition to endangering the ecosystem, dust storms have direct and indirect impacts on public health and human health.[8,20,21,24] Due to their small sizes, almost all dust storm particles, that is, airborne particles (PM) can enter the respiratory tract[25]; larger particles are often deposited in the upper respiratory tract (nasopharyngeal region, tracheobronchial region), while smaller particles can enter deep lung tissue.[26,27] The physical, biological, and chemical properties of these particles can cause disorders in the health of the body,[8,24,26] and in addition to the respiratory tract, can damage other systems of the body, including the cerebral, cardiovascular, skin,[8,24,26] blood, and immune systems.[28,29]

Research has indicated that exposure to dust particles, which can remain in the air from hours to days,[24] can result in other problems like conjunctivitis, meningitis, and valley fever.[24,26,30] In rare cases, it can even lead to death.[26,31] Evidence further suggests that frequent exposure to dust storms can lead to increased adverse health effects[24,32-37] in people of almost all age groups and genders.[3,38,39] People with a history of diabetes, hypertension, cerebrovascular, or pulmonary disease are also at higher risk.[40] 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[41-43] and by assessing the correlation between dust storms or PM_{10} exposure and health outcomes.[32,44] 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.[45] Pérez et al. stated that increased PM during dust storms caused a significant increase in mortality rate in Barcelona.[46] Chen et al.,[47] Kashima et al.,[48] and Delangizan[49] also noted that increased PM_{10} 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,[28,29] have adverse effects on pulmonary function,[50] and increase the number of asthma patients.[51-52] 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.[43,53-55] For example, in studies conducted in Italy,[53] Greece,[54] Kuwait,[43] and Taipei,[55] researchers found no significant relationship between dust storms and increased risk of death. Bell,[56] Ueda,[57] and Min[58] also found that dust storms did not significantly increase hospitalizations of asthmatic patients or asthma attacks in Taipei and Japan.[56]

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.[59] 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); those in which dust storm was a major problem and those in which health indicators were analyzed were included 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

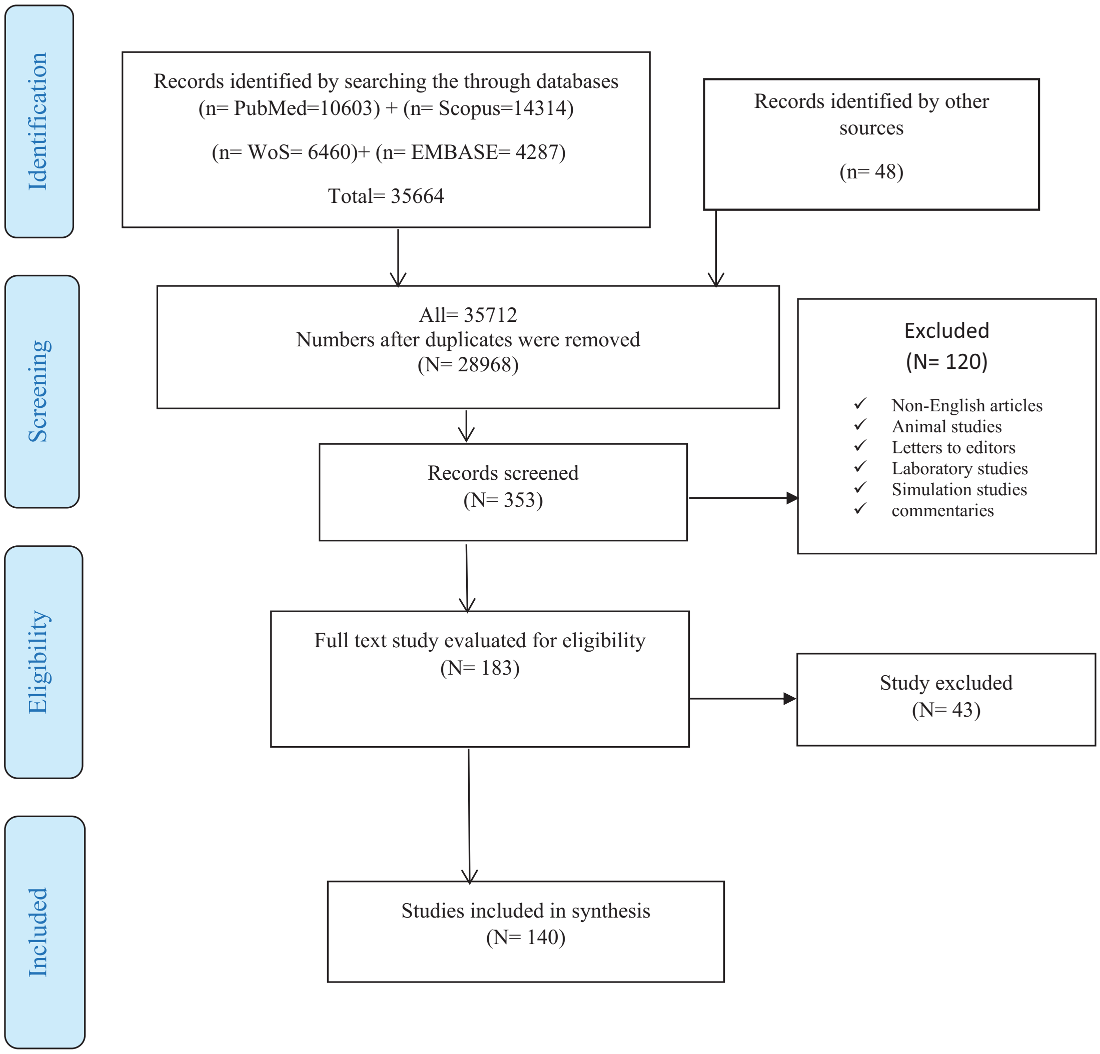

Figure 1. PRISMA flow diagram.

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 35 712 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;

Table 1. Published studies on adverse health effects of dust storms.

REFERENCE	FIRST AUTHOR AND YEAR	STUDY LOCATION	POPULATION (AGE, GENDER)	PM FRACTION	STUDY DESIGN/ METHODOLOGY	HEALTH OUTCOMES	RESULTS
All-cause mortality							
Al et al.[86]	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[43]	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 (0.96–1.012) All-cause mortality, RR 0.99 (0.97–1.00)
Chan and Ng[38]	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 (1.038–0.941)
Chen et al.[39]	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.[3]	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% ($p = 0.018$) $Lags_{0-5}$ 2.7% ($p = 0.023$)
Díaz et al.[68]	Díaz 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.[69]	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.[70]	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.[71]	Jimenez et al. (2010)	Madrid (Spain)	Elderly	PM_{10}, $PM_{2.5}$ or $PM_{10-2.5}$	Ecological time series/ Poisson regression models	Mortality	PM_{10} Total mortality, lag_3 1.02 (1.01–1.04) Circulatory, lag_3 1.04 (1.01–1.06) Respiratory, lag_1 1.03 (1.00–1.06)
Johnston et al.[72]	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_3, OR 1.16 (1.03–1.30)

(Continued)

Table 1. (Continued)

REFERENCE	FIRST AUTHOR AND YEAR	STUDY LOCATION	POPULATION (AGE, GENDER)	PM FRACTION	STUDY DESIGN/ METHODOLOGY	HEALTH OUTCOMES	RESULTS
Kashima et al.[73]	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_1 RR: 1.006 (1.000 1.011)
Kashima et al.[48]	Kashima et al. (2012)	Western Japan	Aged 65 or above l	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.[87]	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.[74]	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.[83]	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.[55]	Lee et al. (2014)	(Seoul, Korea; Taipei, Taiwan, Kitakyushu, Japan)	All ages/all gender	PM_{10}	Ecological time-series using/GAM with Quasi-Poisson distribution	Mortality	Seoul: Under 65 years old (lag_2: 4.44%, lag_3: 5%, and lag_4: 4.39%) Kitakyushu: Respiratory mortality (lag_2: 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.[75]	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_2 <65 years, 2.52% (0.06, 5.04) Male 2.4% (0.43, 4.4) Lag_3 <65 years, lag_3 2.49% (0.07, 4.97) Total non-accidental: 1.57% (0.11, 3.06) Male: 2.24% (0.28, 4.0) <65 years: 2.43% (0.01, 4.91) lag_5 cardiovascular: 3.7% (0.93, 6.54)
Lee et al.[76]	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)

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Table 1. (Continued)

REFERENCE	FIRST AUTHOR AND YEAR	STUDY LOCATION	POPULATION (AGE, GENDER)	PM FRACTION	STUDY DESIGN/ METHODOLOGY	HEALTH OUTCOMES	RESULTS
Mallone et al.[84]	Mallone et al. (2011)	Rome, Italy	⩾35 years/all gender	$PM_{2.5}$, $PM_{2.5–10}$, and PM_{10}	Case-crossover/ Poisson regression model	Mortality	$PM_{2.5–10}$ 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.[46]	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_1, OR 1.084 (1.015, 1.158)
Perez et al.[85]	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) 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) 1.074 (0.998, 1.156) $p<0.1$
Renzi et al.[77]	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.[50]	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.[88]	Schwartz et al. (1999)	Six United States. cities	All ages/all gender	PM_{10}	Ecological/GAM with Poisson regression	Mortality	Mortality, RR 0.99 (0.81–1.22)
Sajani et al.[53]	Sajani et al. (2011)	Emilia-Romagna (Italy)	All ages/all 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.[78]	Stafoggia et al. (2016)	Southern European cities-Spain, France, Italy, Greece	All ages/all gender	PM_{10}	Case-crossover/ Poisson regression models	Mortality	Natural mortality $lag_{0–1,}$ IR 0.65% (0.24–1.06)
Shahsavani et al.[79]	Shahsavani et al. (2019)	Tehran and Ahvaz, IRAN	All ages/all gender	PM_{10}	Case crossover/ conditional Poisson regression models	Mortality	Daily mortality 3.28 (2.42–4.15)
Tobias et al.[80]	Tobias et al. (2011)	Madrid (Spain)	All ages/all gender	$PM_{2.5}$ and PM10–2.5	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% ($P=0.01$)

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Table 1. (Continued)

REFERENCE	FIRST AUTHOR AND YEAR	STUDY LOCATION	POPULATION (AGE, GENDER)	PM FRACTION	STUDY DESIGN/ METHODOLOGY	HEALTH OUTCOMES	RESULTS
Wang and Lin[81]	Wang and Lin (2015)	Metropolitan Taipei	All ages/all gender	PM_{10}	Ecological time series/ distributed lag non-linear model	Mortality	All-cause mortality $lag_{0\text{-}5}$, RR 1.10 (1.04–1.17) Elders 1.10 (1.02–1.18) Elderly circulatory Mortality $lag_{0\text{-}5}$, RR 1.21 (1.02–1.44)
Samoli et al.[54]	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.[82]	Neophytou et al. (2013)	Nicosia, Cyprus	All ages/all gender	PM_{10}	Ecological time-series/GAM	Mortality	Total nom accidental, IR 0.13% (1.03, 1.30) Cardiovascular mortality, IR 2.43 (0.53–4.37) Respiratory mortality, IR 0.79 (4.69, 3.28)
Goto et al.[60]	Goto et al. (2010)	Western Japan	All ages/all gender	–	Ecological time-series/Spearman's rank correlation	Bronchial asthma mortality	Asthma mortality ($r=0.268$, $n=8$, $P>0.05$)
Achilleos et al.[41]	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)
Emergency dispatch or air medical retrieval service							
Holyoak et al.[90]	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.[42]	Aghababaeian et al. (2019)	Iran/dezful	All ages/all gender	PM_{10}	Ecological time-series /GAM	Emergency dispatch of cardiovascular, respiratory and traffic accident missions	RR of Emergency dispatch Lag_2 1.008 (1.001–1.016)/ female/18–60 years/>60 years Lag_3 1.008 (1.00 1.01) Lag_4 1.008 (1.00–1.01) Lag_5 1.008 (1.00–1.01) Lag_6 1.007 (1.00–1.01) Lag_7 1.006 (1.000–1.01) $Lag_{0\text{-}7}$ 1.06 (1.01–1.12) $Lag_{0\text{-}14}$ 1.09 (1.01–1.17) >60 years 1.28 (1.08–1.52) Cardiovascular Problems $Lag_{0\text{-}14}$ 1.33 (1.17–1.50) Respiratory problems $Lag_{0\text{-}14}$ 1.13 (0.93–1.38) Traffic Accident Trauma $Lag_{0\text{-}14}$ 1.03 (0.94–1.13)

(Continued)

Table 1. (Continued)

REFERENCE	FIRST AUTHOR AND YEAR	STUDY LOCATION	POPULATION (AGE, GENDER)	PM FRACTION	STUDY DESIGN/ METHODOLOGY	HEALTH OUTCOMES	RESULTS
Kashima et al.[89]	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, $lag_{0\text{-}3}$ 1.02 (1.00–1.03) Cardiovascular, Lag_0 1.016 (1.001–1.032) Cerebrovascular, Lag_0 1.028 (1.007–1.049) Pulmonary, Lag_0 1.005 (0.986–1.025)
Ueda et al.[61]	Ueda et al. (2012)	Nagasaki, Japan	All ages/all gender	SPM	Case-crossover/ conditional logistic regression	Emergency ambulance dispatches	All causes lag_{0-3} 12.1% (2.3–22.9) Cardiovascular diseases 20.8% (3.5–40.9)
Visits							
Akpinar-Elci et al.[137]	Akpinar-Elci et al. (2015)	Grenada, Caribbean	All ages/all gender	–	Ecological/regression analysis	Asthma visits	Asthma (R2 = 0.036, $p < 0.001$)
Cadelis et al.[138]	Cadelis et al. (2014)	Guadeloupe (Caribbean)	Children/all gender	PM_{10}, $PM_{2.5\text{-}10}$	Case-crossover/t-test and Mann-Whitney	Visits of children due to asthmatic conditions	PM_{10} Lag_0 IR 9.1% (7.1–11.1) Lag_{0-1} IR 5.1% (1.8–7.7) $PM_{2.5-10}$ Lag_0 IR 4.5% (3.3–5) Lag_{0-1} IR: 4.7% (2.5–6.5)
Carlsen et al.[142]	Carlsen et al. (2015)	Reykjavík, Iceland	All ages/all gender	PM_{10}	Ecological time-series study/generalized additive regression model	Emergency hospital visits	Emergency hospital visits 5.8% ($p = 0.02$)
Chan et al.[143]	Chan et al. (2008)	Taipei, Taiwan	All ages/all gender	PM_{10}	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.[144]	Chien et al. (2014)	Taipei, Taiwan	Children	PM_{10}	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.[146]	Chien et al. (2012)	Taipei, Taiwan	Children	PM_{10}	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.[147]	Hefflin et al. (1994)	Washington, United States	All ages/all gender	PM_{10}	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.[148]	Lin et al. (2016)	Taipei, Taiwan	All ages/all gender	PM_{10}	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)

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Table 1. (Continued)

REFERENCE	FIRST AUTHOR AND YEAR	STUDY LOCATION	POPULATION (AGE, GENDER)	PM FRACTION	STUDY DESIGN/ METHODOLOGY	HEALTH OUTCOMES	RESULTS
Liu and Liao[149]	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_3 OR 1.83 (1.212–2.786) Lag_4 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)	Minqin, China	All ages/all gender	–	Ecological time series/ generated regression model	Pulmonary tuberculosis (PTB) visits	PTB visits, R2 = 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

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Table 1. (Continued)

REFERENCE	FIRST AUTHOR AND YEAR	STUDY LOCATION	POPULATION (AGE, GENDER)	PM FRACTION	STUDY DESIGN/ METHODOLOGY	HEALTH OUTCOMES	RESULTS
Yang[145]	Yang (2006)	Taipe, Taiwan	All ages/all gender	PM_{10}	Case-crossover/ Poisson regression model	Conjunctivitis visit	Lag_0 RR 1.02 (0.88–7.99) Lag_1 RR 0.99 (0.86–7.46) Lag_2 RR 0.95 (0.83–6.93) Lag_3 RR 0.97 (0.85–7.11) Lag_4 RR 1.11 (0.97–9.41) Lag_5 RR 0.95 (0.84–6.86)
Lorentzou et al.[122]	Lorentzou et al. (2019)	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 $p=0.128$ Allergy cases 0.929 $p=0.000$ Dyspnea cases 0.464 $p=0.041$
Trianti et al.[52]	Trianti et al. (2017)	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) 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.[150]	Yang et al. (2015)	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) 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 al.[32]	Altindag et al. (2017)	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 ($P=0.10$) Low birth weight, 0.0001 ($P=0.000$) Gestation −0.001 ($P=0.001$) Prematurity, 0.0001 ($P=0.000$) Growth, −0.005 ($P=0.003$)
Dadvand et al.[169]	Dadvand et al. (2011)	Barcelona/Spain	Pregnant woman	PM_{10}	Cohort/linear regression models-logistic regression model	Pregnancy complications	Birth weight −2.1 (−5.8, 1.7) Gestation 0.5 (0.4, 0.6) Preeclampsia 0.98 (0.91, 1.07)
Li et al.[33]	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.[34]	Viel et al. (2019)	Guadeloupe (French West Indies)	909 pregnant women	PM_{10}	Cohort/multivariate logistic regression models	Preterm births	OR 1.40, (1.08–1.81)

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Table 1. (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	PM_{10}	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, PM_{10}	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 PM_{10} Entire Lanzhou city, 0.260 Downtown Lanzhou, 0.342 Dust events, Excess measles Zhangye, 39.1 (17.3–87.6) 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	Daily number of outpatients Daily number of inpatients	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	PM_{10}	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	PM_{10}	Ecological/correlation coefficient	Patient presented to the emergency department (ED) with acute asthma	Acute asthma, $r=-0.14$, ($P=0.45$) Admission rate, $r=-0.08$, ($P=0.65$)

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Table 1. (Continued)

REFERENCE	FIRST AUTHOR AND YEAR	STUDY LOCATION	POPULATION (AGE, GENDER)	PM FRACTION	STUDY DESIGN/ METHODOLOGY	HEALTH OUTCOMES	RESULTS
Alessandrini et al.[92]	Alessandrini et al. (2013)	Rome, Italy	Less than 14 years or 35 years or more	$PM_{2.5}$, $PM_{2.5\text{-}10}$ 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 $diseases_{0-14}$ −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_{0-5} 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.[93]	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-Taiar[51]	Al-Taiar (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[127]	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.[56]	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_2 16.17 (1.17, 33.39)
Chan et al.[135]	Chan et al. (2018)	Nationwide/ Taiwan	All ages/all gender	Total atmospheric PM	Ecological time-series/autoregressive model-ARMAX regression	Diabetes hospitalization	Diabetes lag1 27.41 ($p=0.04$)
Chen and Yang[94]	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%) $P > 0.05$

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Table 1. (Continued)

REFERENCE	FIRST AUTHOR AND YEAR	STUDY LOCATION	POPULATION (AGE, GENDER)	PM FRACTION	STUDY DESIGN/ METHODOLOGY	HEALTH OUTCOMES	RESULTS
Cheng et al.[119]	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.[121]	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.[59]	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.[107]	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.[92]	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 ($P > 0.05$)
Ebrahimi et al.[64]	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.[11]	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.[131]	Kamouchi et al. (2012)	Fukuoka, Japan	20 years and older/all gender	–	Case-crossover/ conditional logistic regression	Ischemic stroke	Overall///Atherothrombotic Z D7 lag_{0-1}, OR 1.07 0.93–1.23///1.44 1.08–1.91 lag_{0-2}, OR 1.04 0.97–1.18///1.48 1.14–1.93 lag_{0-3}, OR 1.02 0.90–1.15///1.37 1.06–1.76 lag_{0-4}, OR 1.02 0.90–1.14///1.35 1.06–1.73 lag_{0-5}, OR 1.02 0.91–1.15///1.35 1.06–1.72
Kanatani et al.[115]	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)

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Table 1. (Continued)

REFERENCE	FIRST AUTHOR AND YEAR	STUDY LOCATION	POPULATION (AGE, GENDER)	PM FRACTION	STUDY DESIGN/ METHODOLOGY	HEALTH OUTCOMES	RESULTS
Kang et al.[120]	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 ($P=0.001$)
Kang et al.[132]	Kang et al. (2013)	Taiwan	All ages/all gender	PM	Ecological time series/ ARIMA method (auto-regressive integrated moving average)	Stroke hospitalization	Stroke admissions (239.6), post-DS days (249.2) ($p<0.001$)
Kashima et al.[40]	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: 0.99 (0.97, 1.01) Cerebrovascular OR: 1.15 (1.01, 1.31)
Khaniabadi et al.[87]	Khaniabadi et al. (2017)	Khorramabad (Iran)	All ages/all gender	PM_{10}	Ecological time series/ AirQ model	Hospitalizations for chronic obstructive pulmonary disease (COPD)	COPD, ER, 7.3% (4.9, 19.5)
Khaniabadi et al.[95]	Khaniabadi et al. (2017)	Ilam, Iran	All ages/all gender	PM_{10}	Ecological time series/ AirQ model	Cardiovascular and respiratory admissions	Respiratory diseases 4.7% (3.2–6.7%) Cardiovascular diseases, 4.2% (2.6–5.8%)
Ko et al.[136]	Ko et al. (2016)	Fukuok- western Japan	Men, Women ratio 30,15 Age, 49.6 ± 22.7	–	Cohort design/t-test	Acute conjunctivitis	Conjunctivitis scores $P<0.05$
Kojima et al.[98]	Kojima et al. (2017)	Kumamoto, Japan	20 years of age or older/all gender	$PM_{2.5}$	Case-crossover/ conditional logistic regression model	Acute myocardial infarction (AMI)	AMI OR, 1.46 (1.09–1.95) Non ST-segment OR 2.03 (1.30–3.15)
Lai and Cheng[109]	Lai and Cheng (2008)	Taipei, Taiwan	All ages/all gender	PM_{10}	Case-control/Z test	Respiratory admissions	Elderly RR 3.44; (0.03–380.1) All age RR 1.04; (0.30–3.16) Pre-school RR, 1.01 (0.26–3.89)
Lee and Lee[117]	Lee and Lee (2014)	Seoul, Korea	All ages/all gender	PM_{10}	Ecological time series patterns/paired t-test	Daily asthma patients	Lag0, 3.79 $p=0.4$ Lag_1, 4.85 $p=0.3$ Lag_2, 11.02 $p=0.1$ Lag3, 15.46 $p=0.06$ Lag_4, 18.05 $p=0.03$ Lag_5, 17.76 $p=0.02$ Lag_6, 18.18 $p=0.01$
Lorentzou et al.[122]	Lorentzou et al. (2019)	Heraklion in Crete Island, Greece	All ages/all gender	PM_{10}	Ecological/one-way ANOVA and Pearson correlation	COPD morbidity	COPD exacerbations, 3.0 (0.8–5.2) Dyspnea admissions, 0.71 ($p=0.001$) COPD admissions, 0.813 $p=0.000$

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Table 1. (Continued)

REFERENCE	FIRST AUTHOR AND YEAR	STUDY LOCATION	POPULATION (AGE, GENDER)	PM FRACTION	STUDY DESIGN/ METHODOLOGY	HEALTH OUTCOMES	RESULTS
Matsukawa et al.[99]	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_4 OR 1.33 (1.05–1.69) Lag_{0-4} OR 1.20 (1.02–1.40)
Menendez et al.[128]	Menendez et al. (2017)	Gran Canaria, Spain	Adults (age 14–80 years) and >80/all gender	PM_{10}	Epidemiological survey/(ANOVA) and Spearman correlation coefficients (ρ)	Health condition of the allergic population	ρ (p-values) Pneumony 0.2 (0.5) Asthma 0.8 (0.0) COPD 0.0 (1.0)
Meng and Lu[96]	Meng and Lu (2007)	Minqin, China	All ages/all gender	–	Ecological time-series/GAM	Daily hospitalization for respiratory and cardiovascular diseases	Respiratory hospitalization, lag_3 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_6 Males, RR 1.17 (1.00–1.38) Hypertension, Lag_3 Males, RR 1.30 (1.03, 1.64)
Middleton et al.[97]	Middleton et al. (2008)	Nicosia, Cyprus	All ages/all gender	PM_{10}	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.[103]	Nakamura et al. (2015)	All-Japan	All ages/all gender	SPM	Case-crossover/ conditional logistic models	Out-of-hospital cardiac arrests	Cardiac arrests, lag_1 OR Model 1 1.00 (0.97–1.19) Model 2 1.08 (0.97–1.20)
Nastos, et al.[104]	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.[50]	Pirsaheb et al. (2016)	Kermanshah, Iran	All ages/all gender	PM_{10}	Ecological/regression	Respiratory disease	Respiratory infection $P \leqslant 0.05$ Chronic pulmonary disease $P \leqslant 0.05$ COPD $P > 0.05$ Angina $P > 0.05$ Asthma $P > 0.05$
Prospero et al.[129]	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.[133]	Radmanesh et al. (2019)	Abadan, Iran	All ages/all gender	PM_{10}	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.[110]	Reyes et al. (2014)	Madrid (Spain)	All ages/all gender	$PM_{10-2.5}$	Ecological time series/ conditional logistic regression model	Hospital admissions	Respiratory admissions, Lag_7 RR 1.031 (1.002 1.060)

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Table 1. (Continued)

REFERENCE	FIRST AUTHOR AND YEAR	STUDY LOCATION	POPULATION (AGE, GENDER)	PM FRACTION	STUDY DESIGN/ METHODOLOGY	HEALTH OUTCOMES	RESULTS
Rutherford, et al.[118]	Rutherford, et al. (1999)	Brisbane, Australia	All ages/all gender	TSP	Cross sectional/paired two-tailed t-tests	Impact on asthma severity	Asthma severity, $P \leqslant 0.05$ In General $P > 0.05$
Stafoggia et al.[78]	Stafoggia et al. (2016)	Southern European cities-Spain, France, Italy, Greece	All ages/all gender	PM_{10}	Case-crossover/"Poisson regression models	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.[101]	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.[111]	Tao et al. (2012)	Lanzhou, China	All ages/all gender	PM_{10}	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.[100]	Teng et al. (2016)	Taipei, Taiwan	All ages/all gender	PM_{10}	Ecological time series/ autoregressive with exogenous variables model	Daily acute myocardial infarction hospital admissions	AMI hospitalizations, 3.2 more
Thalib and Al-Taiar[51]	Thalib and Al-Taiar (2012)	Kuwait	All ages/all gender	PM_{10}	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.[57]	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, $lag_{2,3}$ OR 1.041 (1.013–1.070)
Vodonos et al.[123]	Vodonos et al. (2014)	Be'er Sheva, Israel	All ages/all gender	PM_{10}	Ecological time series/ GAM	Hospitalizations due to exacerbation of COPD	COPD exacerbation: IR 1.16 ($p < 0.001$)
Vodonos et al.[2]	Vodonos et al. (2015)	Be'er Sheva, Israel	Above 18 years old/all gender	PM_{10}	Case crossover/GAM	Cardiovascular Morbidity	Acute coronary syndrome (lag1); OR = 1.007 (1.002–1.012).
Wang et al.[113]	Wang et al. (2014)	Taiwan,	All ages/all gender	PM_{10}	Ecological time series/ ARIMAX regression model	Asthma admissions	Asthma, $Lag_{1\text{-}3}$ average of 17–20 ($p < 0.05$) more hospitalized
Wang et al.[125]	Wang et al. (2015)	Minqin 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.[114]	Watanabe et al. (2014)	Western Japan	Aged À18 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 $p = 0.003$

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Table 1. (Continued)

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_3 RR 1.15 (1.01–10.10)
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_1 RR 1.114 (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_2 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, $\chi 2 = 0.71$ Cardiac 0.91, $\chi 2 = 0.54$)
Cheng et al.[65]	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_2 1.044 (0.999–1.092) Lag_3 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.[162]	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_0, −1.76 (−3.30, −0.21) Lag_{0-1}, −1.54 (−2.84, −0.25) Lag_{0-2}, −1.05 (−2.21, 0.11) Lag_{0-3}, −1.09 (−2.18, −0.01)

(Continued)

Table 1. (Continued)

REFERENCE	FIRST AUTHOR AND YEAR	STUDY LOCATION	POPULATION (AGE, GENDER)	PM FRACTION	STUDY DESIGN/ METHODOLOGY	HEALTH OUTCOMES	RESULTS
Watanabe et al.[161]	Watanabe et al. (2016)	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.[66]	Watanabe et al. (2015)	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.[160]	Yoo et al. (2008)	Seoul, Korea	Children	PM_{10}	Prospective/Pearson correlation tests/ paired t-test	Respiratory symptoms and peak expiratory flow	PEF decreased ($p < 0.05$)
Watanabe et al.[158]	Watanabe et al. (2016)	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.[159]	Watanabe et al. (2015)	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.[163]	Park et al. (2005)	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.[166]	O'Hara et al. (2001)	Karakalpakstan, Uzbekistan	Children aged 7 to 11	PM_{10}	Cross-sectional survey/multivariate regression model	Lung function	There was an inverse relationship between dust event and Lung function
Other impacts							
Lee et al.[168]	Lee et al. (2019)	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.[106]	Soy et al. (2016)	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.[167]	Islam et al. (2019)	Saudi Arabia	All ages/all gender	–	Ecological/panel regression models	Road traffic accidents	$P \leqslant 0.05$
Mu et al.[117]	Mu et al. (2010)	Choyr City, Mongolia	44.2 ± 17.3/all gender	–	Cross-sectional/ student's t-test/ multiple regression analysis	Health-related Quality of Life	Decreased HRQL $P < 0.05$

(Continued)

Table 1. (Continued)

REFERENCE	FIRST AUTHOR AND YEAR	STUDY LOCATION	POPULATION (AGE, GENDER)	PM FRACTION	STUDY DESIGN/ METHODOLOGY	HEALTH OUTCOMES	RESULTS
Sing and symptom							
Higashi et al.[151]	Higashi et al. (2014)	Japan	Aged 23–84 years all gender	$PM_{2.5}$	Panel study/logistic regression with a generalized estimating equation	Daily cough occurrence in patients with chronic cough	Grade 1, 1.111 (0.995, 1.239) Grade 2, 1.171 (1.006, 1.363) Grade 3, 1.357 (1.029, 1.788) Grade 4, 1.414 (0.983, 2.036)
Higashi et al.[152]	Higashi et al. (2014)	Kanazawa, Japan	Between 23 and 84	TSP	Cohort study, McNamara's test	Cough and allergic symptoms in adult with chronic cough	Cough $p = 0.02$
Watanabe et al.[67]	Watanabe et al. (2012)	Japan	Age 63.4 ± 15.2/ all gender	SPM	Descriptive telephone survey/multivariate logistic regression analysis	Lower respiratory tract symptoms in asthma patients	Exacerbation 4% Unaffected 48%
Otani et al.[153]	Otani et al. (2011)	Yonago, Japan	all gender/mean age of 36.2 ± 12.5 years	SPM	Ecological Time-series/t test/Pearson's correlation coefficient	Daily symptoms	All symptoms ($p = 0.020$) Skin symptom ($p < 0.001$)
Onishi et al.[154]	Onishi et al. (2012)	Yonago, Japan	All gender/mean age-SD: 36.2–12.5 years	SPM	Prospective/ Wilcoxon's rank test	Symptom nasal/ ocular/respiratory/ throat /skin symptoms	All symptom increased
Mu et al.[35]	Mu et al. (2011)	Mongolia	35–44/all gender	–	Descriptive studies/ cross-sectional study/ multiple logistic regression analysis	Eye and respiratory system symptoms	Itchy eye $P = 0.3$ Bloodshot eye $P = 0.02$ Lacrimation $P = 0.001$ Respiratory system $P > 0.05$
Majbauddin et al.[155]	Majbauddin et al. (2016)	Yonago, Japan	Mean age of 33.57 ± 1/all gender	SPM	Prospective web-based survey/ student's *t*-test	Daily symptoms	Ocular, $r = 0.47$ ($P < 0.01$) Nasal, $r = 0.61$ ($P < 0.001$) Skin, $r = 0.445$ ($P < 0.05$)
Kanatani et al.[164]	Kanatani et al. (2016)	Kyoto, Tottori, Toyama, Japan	Pregnant women	SPM	Observational study/ Cohort/conditional logistic regression analysis	Allergic symptoms	Allergic symptoms, OR 1.10 (1.04–1.18)
Yoo et al.[160]	Yoo et al. (2008)	Seoul, Korea	Children	PM_{10}	Prospective/Pearson correlation tests/ paired t-test	Respiratory symptoms in children with mild asthma	Cough 42.9 ± 20.8 ($p < 0.05$) Runny/stuffed nose 53.8 ± 19.2 ($p < 0.05$) Sore throat 24.2 ± 13.5 ($p < 0.05$) Eye irritation 24.5 ± 18.1 ($p < 0.05$) Limited physical activity 16.2 ± 12.5 Nocturnal awakening 15.7 ± 14.1 Shortness of breath 20.1 ± 13.8 ($p < 0.05$) Wheeze 16.7 ± 7.1 ($p < 0.05$)

(Continued)

Table 1. (Continued)

REFERENCE	FIRST AUTHOR AND YEAR	STUDY LOCATION	POPULATION (AGE, GENDER)	PM FRACTION	STUDY DESIGN/ METHODOLOGY	HEALTH OUTCOMES	RESULTS
Watanabe et al.[159]	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.[163]	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.[166]	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.[165]	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.[156]	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 diseases; 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; $PM_{2.5\text{-}10}$, 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.

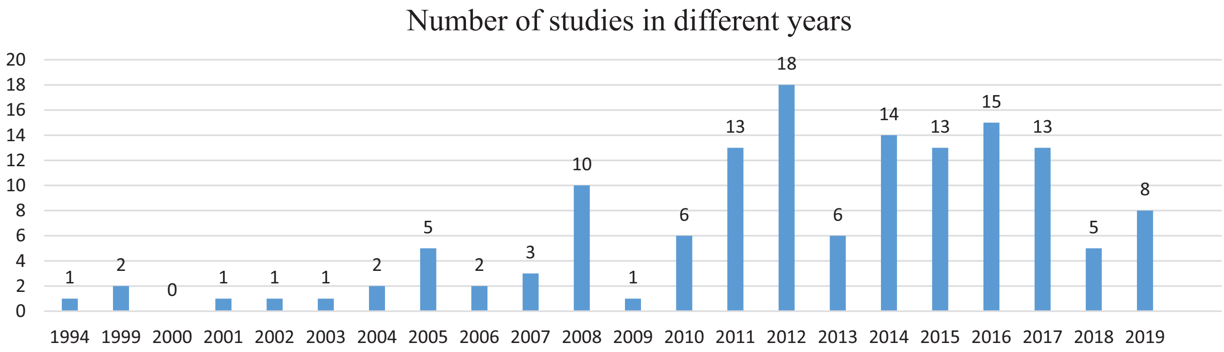

Chart 1. Number of studies of the impact of dust storms on health in different years.

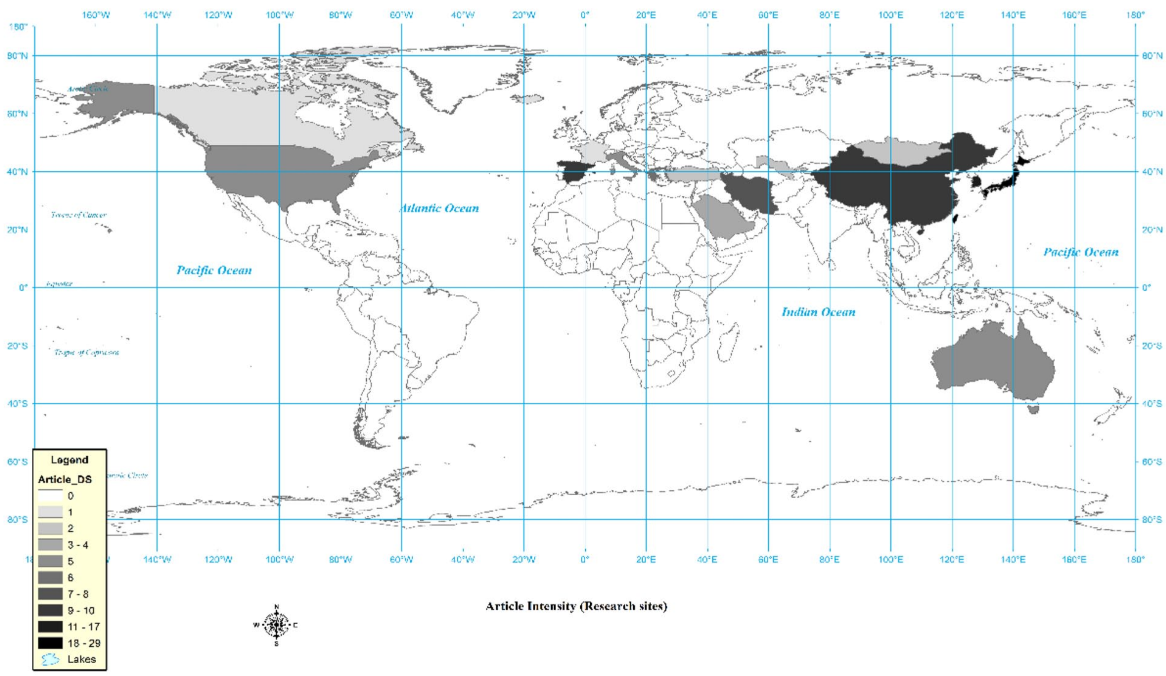

Figure 2. Locations of dust storms and health impact research, 1994–2019.

- 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,[3,38,39,41,46,53-55,68-82] cardiovascular deaths,[3,38,39,48,50,53,70,74,77,82-85] mortality due to acute coronary syndrome (ACS),[3,70,81,86] and respiratory mortality.[48,53,55,77,87] Some studies reported, however, that the number of cases was not increased significantly for all-causes,[43,88] respiratory,[38,43] cardiovascular,[43] or cerebrovascular mortality.[69] Neophytou et al.[82] in Nicosia reported that associations for respiratory mortality was −0.79 (−4.69, 3.28) on dust storm days. Lee et al.[55] 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,[42] increased daily ambulance calls due to respiratory, cardiovascular, and all causes,[89] and an increase in emergency dispatches due to cardiovascular, respiratory, injury and all causes.[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[91]; (2) odds ratio of admission and hospitalization due to congestive cardiac failure[86] and acute coronary syndrome[2,86]; (3) effects on cardiac diseases[92]; (4) risk of CVD hospitalization or admission[40,78,93-97]; (5) emergency admissions for CVD[92]; (6) the impacts on acute myocardial infarction (AMI)[98-100]; (7) emergency hospital admissions for ischemic heart diseases (IHD)[101]; (8) hospital admissions for congestive heart failure (CHF)[102]; and (9) inpatient hospitalization due to cardiac failure.[86] However, some studies reported non-significant results, such as no association between dust storms and out-of-hospital cardiac arrests[103] and no significant changes in admissions concerning cardiovascular syndromes.[104] Also, some reported no significant association between increased dust particles and angina.[50] Bennett et al.[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,[91] respiratory disease hospitalizations or admissions,[11,40,43,51,57,78,92,93,96,104,106-114] cases of bronchial asthma,[93] asthma-related hospitalizations or admissions,[51,57,112-116] cases of aggravated asthma disease,[117,118] daily pneumonia admissions,[119,120] hospital admissions for chronic obstructive pulmonary disease (COPD),[50,87,121-123] emergency hospital admissions for COPD,[124] emergency admissions for respiratory diseases,[92] admitted patients suffering from respiratory infection,[50] and the prevalence of chronic bronchitis, cough, and rhinitis.[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,[126] no significant change in the risk of emergency admission in dust events,[127] and no association between sandstorms and risk of hospital admission for asthma or pneumonia patients.[56] Moreover, some studies reported no statistically significant relationship between increased dust levels and pulmonary function, allergic disease, emergency admission, or drug use[128]; no significant relationship between increased risk of chronic obstructive pulmonary disease, asthma, and angina and increased concentration of dust storms[50,129]; And no excess risk of respiratory hospitalizations.[105] Only two studies found a decrease in respiratory problems after dust storms, like a decreased risk of respiratory inpatients in Taklimakan Desert,[91] and a lower rate of respiration problems among children in areas with higher levels of dust deposition as reported by Wiggs et al.[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,[40,92] the incidence of athero-thrombotic brain infarction,[131] stroke admission rates,[132] hospital admissions for epilepsy problems, cerebral ischemic attacks, and various types of headaches,[133] and daily intracerebral hemorrhagic (ICH) stroke admissions.[134] Bell et al.,[56] however, reported that sandstorms have no significant relationship with the risk of admission to cerebrovascular patients. Moreover, Yang et al.[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.[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.[135] also stated that dust storms were significantly associated with diabetes admissions for females. Furthermore, Ko et al.[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[137-141] cardiac, respiratory, and stroke diagnoses,[142] emergency healthcare visits for IHD, CVD, and COPD,[143] conjunctivitis clinic visits,[144,145] children clinic visits for respiratory problems,[139,146] healthcare visits for respiratory diseases,[52,139,146,147] healthcare visits for all causes, circulatory, and respiratory diseases,[148] and for cardiovascular and respiratory problems.[149,150] Lorentzou et al.[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.[151,152] showed the effects of Kosa on cough. Otani et al.[153] found that the scores for symptoms (nasopharyngeal, ocular, respiratory, and skin) were significantly higher when related to dust storms. Onishi et al.[154]

reported that all symptoms (nasal, ocular, respiratory, throat, and skin) increased after exposure to dust storms. Mu et al.[35] also reported that an increased risk of eye lacrimation occurrence is associated with dust events. Majbauddin et al.[155] reported a positive correlation between the increased concentration of dust storms and ocular, nasal, and skin symptoms. Similarly Meo et al.[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.,[157] Watanabe et al.,[158,159] Yoo et al.[160] and Watanabe et al.[161] all found that dust storms have a significant, negative effect on pulmonary function. Other studies, including Hong et al.,[162] Watanabe et al.[159] and Park et al.[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.[164] Yoo et al.,[160] reported a significant increase in respiratory symptoms during dust storms, and Watanabe et al.[159] reported that sand and dust storms are significantly associated with respiratory symptoms. Moreover, Park et al.[163] reported a relationship between nighttime symptoms and particular matter levels during dust storms. Watanabe et al.[165] also stated that dust storms worsen respiratory symptoms in asthmatic patients, but some studies like O'Hara et al.[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.[167] found that sandstorms and the number of vehicles were significantly responsible for road traffic accidents. Soy et al.[106] reported that dust storms can have adverse effects on the quality of life of patients with asthma and allergies. Mu et al.[117] reported that dust storms can decrease health-related quality of life in everyone exposed to them. Lee et al.[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,[32] and decreased cognitive function in children.[33] Preterm births[34] were correlated with Valley fever incidences[36] and increased spring measles incidence.[44] Only one article was observed to indicate no significant effect of desert dust storms on pregnancy consequences.[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.[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*."[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.[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.[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.[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.[8] Ultimately, the evidence from infectious diseases shows that pathogenic microorganisms are abundant in dust storms,[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.[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,[12] studies show that fine particles in dust storms can enter lung tissue and the bloodstream through chemical interactions,[13] causing a thrombolytic and inflammatory process and the secretion of cytokines in the body.[14,15] Moreover, the toxicity of some of these substances in the body reduces the contractibility of the heart, increases vasoconstriction, and increases blood pressure.[14,18-20] 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.[22-25] 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.[26] Another mechanism that may cause respiratory illnesses following a dust storm is the presence of pathogens such as microorganisms and fungi[37] 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.[22] 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.[22,38,39] 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.[3,40,41]

In 2009, Calderon Garosia stated that pollutants in dust storms can cause problems such as cardiovascular, respiratory, liver, and skin toxicity through systemic inflammation[42] 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.[42-44] In addition, chemical components found in dust storms can enter the brain through the mucosa and olfactory system.[42] After entering the nervous system, they may accumulate in the anterior cortex of the brain and cause problems in emotional regulation and impulse control.[45] 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.[46,47] Inflammation and ischemia increase the risk of decidual bleeding, followed by hematoma formation and placental abruption.[48,49] 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.[50,51]

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[11] 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.[52] I In terms of the quality of life, Mu[53] 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,[43,88] cardiovascular,[103-105] cerebral,[134] and respiratory problems.[127-129] Moreover, some studies reported that dust storms may have a protective effect against non-accidental and respiratory death[55] and other pulmonary problems.[91,130,166]

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.[55,166] Differences in the chemical and physical nature of particulate matters may cause different health outcomes in varying regions.[55] 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.[22] 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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