Atmospheric Environment 79 (2013) 510–517

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Effect of Asian dust storms on daily mortality in seven metropolitan cities of Korea

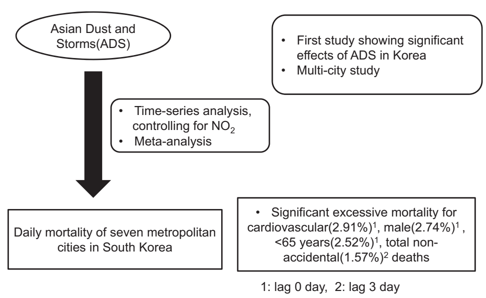
Hyewon Lee [a], Ho Kim [a,*], Yasushi Honda [b], Youn-Hee Lim [c], Seungmuk Yi [a]

[a] Graduate School of Public Health, Seoul National University, Republic of Korea
[b] Faculty of Health and Sport Sciences, University of Tsukuba, Japan
[c] Institute of Health and Environment, Seoul National University, Republic of Korea

HIGHLIGHTS

- We explore the effect of Asian dust storms (ADS) on daily mortality in Korea.
- Meta-analysis is applied for 7 cities to estimate the pooled effects of ADS.
- We firstly show positive and significant associations between ADS and mortality in Korea.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 12 February 2013
Received in revised form
23 June 2013
Accepted 24 June 2013

Keywords:
Asian dust storms
Non-accidental mortality
Lag effects
Pooled effects
Meta-analysis

ABSTRACT

The adverse effects of dust storms on health have been a major issue in several countries. A substantial number of studies have found significant associations between dust storms and morbidity such as emergency visits and hospitalizations. However, the results of the studies on the association between dust storms and mortality are inconsistent. In Korea, no study has found statistically significant effect of Asian dust storms on daily mortality. Thus, this study aims to explore the effect of Asian dust storms on daily mortality in Korea during 2001–2009. All analyses were confined to non-accidental mortality. We used generalized additive model with Quasi-Poisson regressions. We considered the lag effect of dust storms up to 7 days and performed subgroup analyses by disease, sex and age. Current day's temperature, relative humidity, barometric pressure, day of the week, season and time trends were controlled for in a basic model. SO_2, NO_2 and PM_{10} levels were also added in the further analyses. Meta-analysis was applied for seven metropolitan cities in Korea to estimate the pooled effects of Asian dust storms. We reported results as excessive mortality by percentage due to Asian dust storms. We found significant positive associations between Asian dust storms and mortality at lag 0 (cardiovascular: 2.91%; 95% CI: 0.13, 5.77, male: 2.74%; 95% CI: 0.74, 4.77 and <65 years: 2.52%; 95% CI: 0.06, 5.04), at lag 2 (male 2.4%; 95% CI: 0.43, 4.4 and <65 years: 2.49%; 95% CI: 0.07, 4.97), at lag 3 (total non-accidental: 1.57%; 95% CI: 0.11, 3.06, male: 2.24%; 95% CI: 0.28, 4.25 and <65 years: 2.43%; 95% CI: 0.01, 4.91) and at lag 5 (cardiovascular: 3.7%; 95% CI: 0.93, 6.54 and male: 2.04%, 95 CI: 0.08, 4.04) in the model which adjusted for NO_2 additionally. Other models showed similar significant results except the PM_{10}-adjusted model. This is the first study to show the significant relationship between Asian dust storms and mortality in Korea and to present a pooled effect estimate by meta-analysis of multiple cities in a country. Asian dust storms could significantly affect daily mortality in Korea.

* Corresponding author. School of Public Health, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 151-742, Republic of Korea. Fax: +82 2 745 9104.
E-mail address: hokim@snu.ac.kr (H. Kim).

1352-2310/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.atmosenv.2013.06.046

1. Introduction

Dust storms originating in desert regions have affected the neighboring countries adversely in various aspects (Chung, 1992; Chen et al., 2003; Chen and Yang, 2005; Badarinath et al., 2007; Kloor, 2008; Barnett et al., 2012). A recent study reported that dust clouds originating from Taklimakan Desert in China circled the Earth in about 13 days (Uno et al., 2009). This result showed the importance of study on the impacts of dust storms for public health globally. As dust storms affect the entire globe as well as the neighboring countries, more studies on adverse health effects of dust storms are needed. In the recent decades, adverse effects of dust storms on health have been reported and become a major issue in several countries (Lee et al., 2003; Chang et al., 2006; Yang et al., 2009; Kanatani et al., 2010; Holyoak et al., 2011; Sajani et al., 2011; Watanabe et al., 2011; Tam et al., 2012). Some experimental studies found adverse effects of dust storms on health through animal studies and biomarkers (Lei et al., 2004; Meng and Zhang, 2006; Wei and Meng, 2006a, b; Meng and Zhang, 2007). Epidemiological studies also found adverse dust effects on human health with various study designs and statistical methods (Gyan et al., 2005; Chan et al., 2008; Middleton et al., 2008; Johnston et al., 2011). Substantial studies on the association between dust storms and morbidity have shown significant positive associations consistently (Chan et al., 2008; Cheng et al., 2008; Middleton et al., 2008; Monteil, 2008; Yoo et al., 2008; Kanatani et al., 2010), whereas the results of the studies on the association between dust storms and mortality have been inconsistent and are controversial (Kwon et al., 2002; Lee et al., 2007; Mallone et al., 2009; Goto et al., 2010; Hashizume et al., 2011; Johnston et al., 2011; Samoli et al., 2011).

Asian dust storms, which originate in China's northwest, northern, and desert regions of Mongolia, have affected several Asian countries including China, Taiwan, Japan, and Korea (Taylor, 2002; Guo et al., 2004; Kwon and Cho, 2004; Lee et al., 2007; Chan and Ng, 2011), and their adverse health effects have been reported (Chen et al., 2004; Lee et al., 2006; Wei and Meng, 2006a; Watanabe et al., 2011). These countries have reported effects of Asian dust storms on morbidity such as emergency visits and hospitalizations (Yang et al., 2005; Meng and Lu, 2007; Chan et al., 2008; Kanatani et al., 2010). However, regarding the effect of Asian dust storms on mortality, a few studies have found statistically significant results (Chen et al., 2004; Goto et al., 2010; Chan and Ng, 2011; Hashizume et al., 2011). In Korea, there have been a few studies on the effects of Asian dust storms on human health, and some studies have reported significant association between Asian dust storms and adverse health outcomes (Hwang et al., 2003; Kwon and Cho, 2004; Yoo et al., 2008; Hong et al., 2010). However, no study has found significant effects of Asian dust storms on daily mortality (Kwon et al., 2002).

In this study, we aimed to examine the effect of Asian dust storms on daily mortality in Korea during 2001–2009 in a situation where the association between ADS and mortality was found to be inconsistent in the previous studies. We performed a meta-analysis of seven metropolitan cities in Korea after conducting time-series analyses for each of the seven metropolitan cities to estimate the pooled effects of Asian dust storms on Korea. The seven cities account for 48% of the total population of Korea (23.2 million of 48.87 million).

2. Materials and methods

2.1. Data

Seven metropolitan cities including Seoul, the capital of Korea, were selected to estimate the pooled effect of Asian dust storms on daily mortality in Korea: Seoul, Incheon, Busan, Daegu, Daejeon, Gwangju, and Ulsan. Because these cities have different geographical features, each city was affected by Asians dust storms differently in the aspect of the number of Asian dust storm days (Fig. 1).

We obtained daily mortality data from the Korean National Statistical Office for seven metropolitan cities from January 2001 to December 2009. For analyses, we excluded mortality due to accidents [International Classification of Diseases 10th Revision (ICD-10), codes S00-Y99], and examined the effects of Asian dust storms on total non-accidental mortality (codes A00-R99). Asian dust effects on cardiovascular mortality (codes I00-I99) and respiratory mortality (codes J00-J99) were also analyzed separately.

We constructed a dummy value for Asian dust storms (Asian dust storm days and non-Asian dust storm days) (Kwon et al., 2002). Asian dust storm data was obtained from the Korean Meteorological Administration (KMA). KMA defines Asian dust storm days as follows; first, confirm whether dust storms occur in the desert regions of Mongolia and China. Second, if dust storms occurred, observe the movement of dust storms to Korea using weather maps and satellites. Finally, confirm Asian dust storms in Korea with visual observation and issue a dust storm warning. KMA issues a dust storm warning by considering the extent of dust storms according to PM_{10} concentrations: severe dust storms, over 400 μg m^{-3}; and more severe dust storms, over 800 μg m^{-3} for 2 h continually a day. Seven metropolitan cities had different number of Asian dust storm days during January 2001 to December 2009: Seoul-107, Incheon-109, Busan-68, Daegu-82, Daejeon-91, Gwangju-91, and Ulsan-68 (Fig. 1).

To control for potential confounding effects of other related variables, we collected air pollutants data (PM_{10}, SO_2, NO_2, CO, O_3) from the Korean National Institute of Environmental Research (KNIER) and meteorological data (temperature, relative humidity,

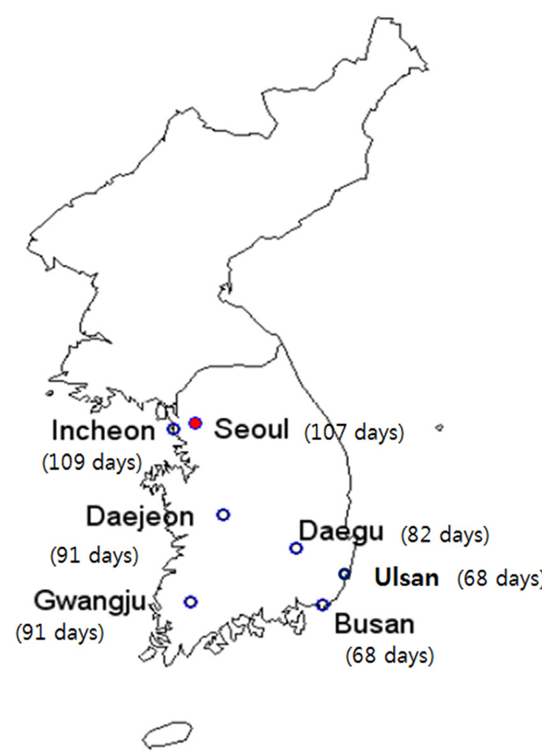


Fig. 1. The geographical distribution of seven metropolitan cities and the number of Asian dust storm days per each metropolitan city in Korea.

barometric pressure) from the Korean Meteorological Administration (KMA). Concentrations of five air pollutants were measured every 15 min at 88 monitoring stations (Seoul: 27, Incheon: 11, Busan: 16, Daegu: 11, Daejeon: 6, Gwangju: 5, Ulsan: 12) during the study period. We calculated daily 24-hr mean concentrations for PM_{10}, SO_2, NO_2 and daily 8-hr max concentrations for CO, O_3. We calculated the daily representative concentration value for each metropolitan city as follows; first, we averaged every hour values of all monitoring stations per each metropolitan city. Second, we calculated daily mean concentrations by averaging the 24 values for PM_{10}, SO_2, NO_2 and chose an 8-hr (09:00–17:00) maximum value for CO, O_3 among averaged hour values per each metropolitan city. We had missing records of air pollutants. When the daily concentrations of air pollutants were missing for all stations of a city, the values were left missing. There were missing values of air pollutant concentrations when we calculated daily values as above (Incheon: 1 day missing of CO, O_3; Busan: 1 day missing of PM_{10}; Daegu: 11 days missing of five air pollutants; Daejeon: 3 days missing of PM_{10}, NO_2, SO_2 and 4 days missing of CO, O_3; Gwangju: 4 days missing of PM_{10}, NO_2, SO_2 and 5 days missing of CO, O_3).

2.2. Statistical analyses

For comparison of summary statistics between Asian dust storm days (ADS days) and Non-Asian dust storm days (Non-ADS days), we confined Non-ADS days to days within the months on which Asian dust storms occurred except for ADS days.

We performed time-series analyses using generalized additive model (GAM) with Quasi-Poisson regressions to estimate the effect of Asian dust storms on daily mortality in each of the seven metropolitan cities (Dominici et al., 2002; Meng and Lu, 2007). We achieved model's robustness with Quasi-Poisson regressions for extreme daily mortality counts (Kwon et al., 2002). Current day's temperature, relative humidity, barometric pressure, day of the week, season and time trends were controlled for in a basic model. We adjusted for season and time trends using smoothing function for time with 4 degree of freedom (df) per year and for temperature, the default value of df was used because df is estimated as part of fitting in GAM (Hastie and Tibshirani, 1986). Estimated df's for temperature were between 1 and 2 in the models. Also, we performed subgroup analyses by disease (cardiovascular disease, respiratory disease), sex (male, female) and age (<65 years old, ≥65 years old).

In further analyses, we added SO_2, NO_2 and PM_{10} to the basic model respectively and presented the results of NO_2-adjusted model. As major source of NO_2 is vehicle exhaust emissions (Nakai et al., 1995; Kirchstetter et al., 1996; Carslaw and Beevers, 2005), we selected this model as the main model for the purpose of controlling for local air pollution. In addition, we considered the single-day lag effect of Asian dust storms up to 7 days, and adjusted for same lag day's air pollutants.

After analyzing the association between Asian dust storms and daily mortality for each of the seven metropolitan cities, we conducted meta-analysis to estimate the effect of Asian dust storms in Korea by pooling the Asian dust storm effect on each metropolitan city. We tested for heterogeneity and used the random-effects model for p-value less than 0.1. Otherwise we used the fixed-effects model.

All analyses were conducted using gam in package MGCV and rma in package METAFOR, R. We reported the results as percentage increase of excess risk due to Asian dust storms.

3. Results

3.1. Descriptive results

Fig. 1 shows the geographical distribution of seven metropolitan cities and the number of Asian dust storm days per each metropolitan city in Korea. As this figure shows, the seven metropolitan cities are dispersed geographically over entire Korea and each of the cities has different number of Asian dust storm days according to the geographical characteristics.

Table 1 displays the absolute number and proportion of non-accidental deaths per each metropolitan city during 2001–2009. We presented the number of stratified deaths by disease, sex and age. There were the most total non-accidental deaths in Seoul (304,850) and the least deaths in Ulsan (31,618) by the difference of the population size. Deaths due to cardiovascular diseases accounted for 23.9% (Gwangju) to 30.8% (Busan), and deaths due to respiratory diseases accounted for 5.7% (Seoul) to 7.5% (Daejeon) of total non-accidental deaths. Deaths for male and deaths for people above 65 years old were higher than deaths for female and deaths for people below 65 years old in all metropolitan cities.

We compared air pollutants and weather variables of Asian dust storm days with the variables of Non-ADS days (Table 2). PM_{10} concentrations during ADS days were much higher than during Non-ADS days in all metropolitan cities. Temperature was higher and barometric pressure was lower during ADS days than during Non-ADS days.

3.2. Effects of Asian dust storms

The pooled effect of Asian dust storms on daily mortality in Korea using meta-analysis was statistically significant. After conducting meta-analysis considering the single-day lag effect of Asian

Table 1
The absolute number and proportion of non-accidental deaths per each seven metropolitan city, Korea during 2001–2009.

	Seoul		Incheon		Busan		Daegu		Daejeon		Gwangju		Ulsan	
Population size in 2005	9,762,546		2,517,680		3,512,547		2,456,016		1,438,551		1,413,644		1,044,934	
Non-accidental deaths	304,850		86,461		149,561		90,478		45,682		46,473		31,618	
Non-accidental mortality per 100,000	3123		3434		4258		3684		3176		3287		3026	
Cause of death														
Cardiovascular	82,141	26.9%	25,052	29.0%	46,076	30.8%	24,426	27.0%	12,368	27.1%	11,100	23.9%	8806	27.9%
Respiratory	17,442	5.7%	5704	6.6%	9088	6.1%	5868	6.5%	3412	7.5%	3043	6.5%	2285	7.2%
Other causes	205,267	67.3%	55,705	64.4%	94,397	63.1%	60,184	66.5%	29,902	65.5%	32,330	69.6%	20,527	64.9%
Sex														
Male	164,870	54.1%	46,894	54.2%	80,825	54.0%	48,300	53.4%	24,210	53.0%	23,894	51.4%	16,687	52.8%
Female	139,980	45.9%	39,567	45.8%	68,736	46.0%	42,178	46.6%	21,472	47.0%	22,579	48.6%	14,931	47.2%
Age(years)														
Age<65	102,009	33.5%	28,966	33.5%	50,683	33.9%	29,127	32.2%	14,148	31.0%	13,918	29.9%	11,035	34.9%
Age≥65	202,824	66.5%	57,493	66.5%	98,867	66.1%	61,351	67.8%	31,531	69.0%	32,553	70.1%	20,580	65.1%

Table 2
Summary statistics for air pollutants and meteorological variables during Asian dust storm days and Non-ADS days in seven metropolitan cities, Korea during 2001–2009.

Environmental variables	Mean (SD)						
Asian dust storm days	Seoul	Incheon	Busan	Daegu	Daejeon	Gwangju	Ulsan
	107 days	109 days	68 days	82 days	91 days	91 days	68 days
PM_{10}($\mu g\ m^{-3}$)	176.4 (159.4)	139.9 (103.8)	171.4 (137.6)	163.6 (130.2)	145.8 (118.1)	144.4 (107.5)	162.3 (135.6)
NO_2(ppb)	34.85 (11.79)	25.16 (10.24)	25.22 (8.55)	23.75 (10.29)	18.01 (8.26)	23.85 (8.73)	20.12 (6.09)
SO_2(ppb)	5.54 (2.05)	7.08 (2.48)	6.79 (3.60)	6.98 (3.21)	5.18 (1.86)	4.43 (1.78)	7.85 (3.16)
CO (ppm)	8.80 (4.36)	8.36 (4.30)	6.90 (2.87)	9.20 (5.28)	10.48 (6.46)	10.04 (5.92)	7.76 (3.60)
O_3(ppb)	34.09 (12.89)	35.94 (11.48)	42.51 (9.91)	40.94 (13.04)	41.72 (14.46)	37.48 (12.06)	42.87 (9.54)
Temperature (°C)	9.09 (6.54)	8.75 (5.71)	12.59 (4.86)	12.24 (6.12)	9.69 (6.36)	9.87 (5.27)	13.13 (5.34)
Relative humidity (%)	55.39 (14.22)	63.34 (14.09)	50.18 (14.99)	41.51 (13.41)	54.17 (13.80)	57.57 (13.85)	43.76 (15.04)
Air pressure (hPa)	1013.5 (5.48)	1013.6 (5.37)	1012.5 (4.67)	1012.6 (5.02)	1013.8 (5.12)	1015.3 (4.39)	1011.6 (4.65)
Non-ADS days[a]	957 days	957 days	755 days	895 days	885 days	883 days	756 days
PM_{10}($\mu g\ m^{-3}$)	65.79 (28.07)	62.82 (25.76)	61.71 (24.41)	61.07 (22.61)	52.52 (21.54)	54.22 (23.13)	55.70 (22.68)
NO_2(ppb)	40.47 (11.96)	30.94 (11.38)	26.68 (8.91)	27.12 (9.11)	21.78 (8.23)	24.78 (8.15)	22.91 (7.01)
SO_2(ppb)	6.10 (2.41)	7.91 (2.56)	6.59 (2.75)	6.65 (2.55)	5.51 (2.01)	4.61 (1.79)	7.80 (2.95)
CO (ppm)	9.10 (4.04)	9.05 (3.82)	6.89 (3.13)	9.22 (3.83)	10.51 (5.77)	9.10 (4.89)	7.30 (3.03)
O_3(ppb)	32.86 (16.43)	36.56 (14.76)	41.49 (13.06)	42.11 (17.25)	38.71 (16.05)	37.86 (14.76)	42.50 (13.08)
Temperature (°C)	8.08 (7.68)	8.03 (7.05)	11.23 (5.34)	10.92 (6.68)	8.29 (7.26)	9.01 (6.51)	11.30 (5.69)
Relative humidity (%)	55.72 (13.97)	61.88 (13.99)	56.50 (17.29)	49.91 (15.44)	58.92 (14.32)	60.89 (12.93)	56.55 (16.22)
Air pressure (hPa)	1018.2 (6.66)	1018.3 (6.64)	1016.9 (6.11)	1017.3 (6.60)	1018.1 (6.89)	1018.9 (6.56)	1016.5 (6.16)

[a] Non-ADS days excluded the months on which Asian dust storms did not occur.

dust storms up to 7 days, we found lag effects of Asian dust storms on mortality for cardiovascular disease, for male and for below 65 years old as a result of subgroup analyses (Fig. 2).

We presented the significant pooled excessive mortality by percentage (result of meta-analysis) and corresponding excessive mortality for each of the seven metropolitan cities associated with Asian dust storms at lag 0 day to lag 3 day (Table 3). Specifically, we found significant positive associations between Asian dust storms and daily mortality at lag 0 (cardiovascular: 2.91%; 95% CI: 0.13, 5.77, male: 2.74%; 95% CI: 0.74, 4.77 and <65 years: 2.52%; 95% CI: 0.06, 5.04), at lag 2 (2.4%; 95% CI: 0.43, 4.4 and <65 years: 2.49%; 95% CI: 0.07, 4.97), at lag 3 (total non-accidental: 1.57%; 95% CI: 0.11, 3.06, male: 2.24%; 95% CI: 0.28, 4.25 and <65 years: 2.43%; 95% CI: 0.01, 4.91) and at lag 5 (cardiovascular: 3.7%; 95% CI: 0.93, 6.54 and male: 2.04%, 95 CI: 0.08, 4.04) in the main model which adjusted for NO_2 additionally. Other models except a PM_{10}-adjusted model showed similar significant results.

4. Discussion

This study found significant positive associations between Asian dust storms and daily mortality in Korea during 2001–2009, especially at lag 0, 2, 3, 5 day. It is the first study to show significant Asian dust storm effects on mortality in Korea. A previous study has suggested a positive association between ADS and mortality in Seoul, Korea, but the result was not statistically significant (Kwon et al., 2002).

The study period of the previous study (Kwon et al., 2002) is from 1995 to 1998, whereas our study period is from 2001 to 2009. There were only 28 Asian dust days during the study period in the previous study and this may lack statistical power as other studies mentioned, whereas in our study 107 ADS days were used for analyses for Seoul. Furthermore, daily mean PM_{10} concentration during ADS days was higher in our study period (176.4 $\mu g\ m^{-3}$) than Kwon et al. (2002) study period (101.1 $\mu g\ m^{-3}$), whereas daily mean PM_{10} concentration during non-ADS days was lower in our study period (65.79 $\mu g\ m^{-3}$) than Kwon et al., 2002 study period (73.3 $\mu g\ m^{-3}$). In other words, as time goes by, Asian dust storms causes much higher PM_{10} concentrations and usual days' PM_{10} concentrations get lower with reduction efforts. Also, we found significant dust effects on male mortality in Seoul at lag 3 (without adjusting for NO_2) and at lag 2, 3 (adjusting for NO_2) but the previous study did not perform a subgroup analysis by sex. In addition, the previous study performed a same statistical method (GAM) and used dummy variables for the dust events as we did in this paper, but used a different statistical tool (S-plus statistical software) and thus methods for smoothing seasonal variation and handling missing values would be different.

This is also the first study which has conducted meta-analysis to estimate the pooled effect of dust storms in a country. Previous studies confined analyses to a city, especially to the capital, so that overall effects of dusts storms in a country could not be estimated (Lee et al., 2007; Chiu et al., 2008; Mallone et al., 2009; Yang et al., 2009). Our study analyzed effects of Asian dust storms on seven metropolitan cities, considering each metropolitan city's different characteristics and estimated pooled effects by conducting meta-analysis. Estimating pooled effects of dust storms in a country could be helpful for the governmental administration to establish a precaution against dust storms for the nation's health.

We found heterogeneity among seven metropolitan cities. The results showed dust effects are different by seven cities regarding lag structure and sensitive subgroups and we intended to examine the pooled effect of Asian dust storms in Korea by performing meta-analysis. Despite the most dust storm days among seven cities, Incheon had an adverse dust effect only on male mortality at lag 0 day up to lag 4 day. Therefore, other regional characteristics such as extent of local air pollution, policy for environment, or other demographical characteristics as well as the number of Asian dust storm days may contribute to heterogeneity among cities.

In addition, we observed statistically significant effects of Asian dust storms on daily mortality after adjusting for air pollutants. Effects of the same dust storm could be different for each country or region, as each country or region has different extent of local air pollution. In Korea, PM_{10} concentrations of usual days are high compared to other countries (Kwon et al., 2002; Mallone et al., 2009; Kanatani et al., 2010; Chan and Ng, 2011; Sajani et al., 2011). We thought that adjusting for air pollutants as a local source may be worth analyzing in that it could be controlling for local air pollution. In a previous study, the significant association between dust storms and daily mortality became insignificant after adjusting for PM_{10} in a basic statistical model (Chan and Ng, 2011). Our study showed similar patterns but our result was significant at lag 5 day in PM_{10}-

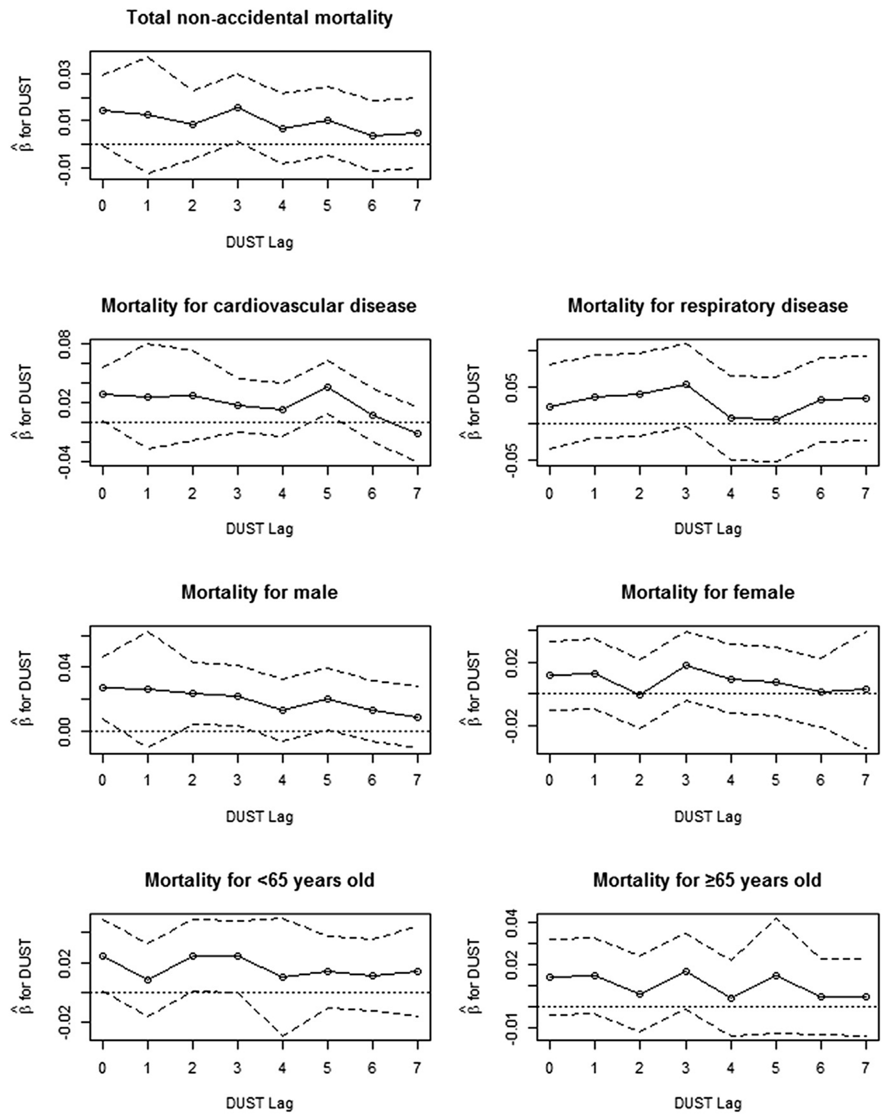


Fig. 2. Pooled excessive mortality (%) and 95% CI associated with Asian dust storms in seven metropolitan cities, Korea during 2001–2009 at lag 0 to lag 7 day after adjusting for NO_2.

adjusted model. Difference between our results and the results of Chan and Ng (2011) may be due to the difference of usual PM_{10} concentrations to which people are exposed or the fact that Chan and Ng (2011) did not examine lag effects longer than lag 1.

In the PM_{10}-adjusted model of this study, we found no significant adverse pooled effects up to lag 4 day and even found significant protective effects in some cities (Busan, Daegu, and Daejeon). In other words, when we adjusted for PM_{10}, mortality was lower on Asian dust storm days than non-ADS days significantly. This may be due to a dust warning effect. That is, if PM_{10} concentrations are constant on both ADS days and non-ADS days, people die less on ADS days because people become careful to dust exposure due to a dust warning system. Our study is the first to show the relationship between Asian dust storms and mortality after adjusting for PM_{10} and other air pollutants. More studies are needed to see what brings about such results.

We observed that Asian dust storms affected mortality a few days after ADS days as well as on ADS days. It is possible that Asian dust storms have not waned completely during a few days and may affect mortality after a few days. In spite of some heterogeneity among cities, we mostly found adverse dust effects on mortality for male and for people younger than 65 years old. It is possible that susceptible people avoid exposure to dust storms on ADS days with a dust warning. In Korea, a dust warning system was first adopted in April, 2002. Susceptible people including women and the elderly may be more cautious not to be affected by dust storms, whereas relatively physically stronger people including men and the young may be less careful even when a dust warning is issued. So, they would be affected by dust storms much more than susceptible people. As a result, our study showed the possibility that a dust warning system could be an effective means to aid people avoid and minimize exposure to dust storms and thus protect people from dust storms.

Most previous studies analyzed effects of dust storms for a short study period (Kwon et al., 2002; Chen et al., 2004; Hwang et al., 2004; Hong et al., 2010). Consequently, it is possible that dust events used in the studies were too small to detect statistically significant effects (Chan and Ng, 2011). Our study used a nine-year dataset, a relatively longer study period compared to the previous studies (Kwon et al., 2002; Hwang et al., 2004). We thought conducting analyses with the longer data period could detect statistical significance of dust storm effects.

Table 3
Excessive mortality (%) and 95% CI associated with Asian dust storms at lag 0 to lag 3 day after adjusting for NO_2.

		Pooled[a]	Seoul	Incheon	Busan	Daegu	Daejeon	Gwangju	Ulsan
lag0	Non-accidental	1.46 (0,3)	1.39 (−0.8,3.7)	2.45 (−1.6,6.7)	−1.1 (−4.8,2.8)	1.05 (−3.4,5.7)	−1.61 (−7.3,4.4)	5.09 (−0.8,11.3)	**9.99 (1.6,19)**
	Cardiovascular	**2.91 (0.1,5.8)**	2.2 (−1.9,6.5)	2.43 (−4.8,10.3)	2.79 (−3.8,9.8)	0.04 (−8.3,9.1)	2.27 (−8.8,14.7)	**15.57 (3,29.7)**	4.58 (−10.5,22.2)
	Respiratory	2.43 (−3.3,8.5)	−3.53 (−11.7,5.3)	2.35 (−12.5,19.7)	8.38 (−6.4,25.5)	6.46 (−10.4,26.5)	5.09 (−15.3,30.4)	11.62 (−10.6,39)	16.32 (−12.7,55)
	Male	**2.74 (0.7,4.8)**	1.99 (−0.9,5)	**5.44 (0.1,11.1)**	−0.88 (−5.9,4.4)	2.45 (−3.5,8.8)	−0.32 (−7.9,7.9)	**9.92 (1.7,18.8)**	**11.78 (0.3,24.6)**
	Female	1.15 (−1,3.4)	2.62 (−0.6,6)	−0.83 (−6.4,5.1)	−0.58 (−6,5.2)	−1.45 (−8,5.5)	1.27 (−7,10.3)	0.12 (−8,9)	7.05 (−4.8,20.3)
	<65	**2.52 (0.1,5)**	0.14 (−3.4,3.8)	5 (−1.6,12.1)	2.84 (−3.3,9.3)	4.17 (−3.5,12.5)	6.88 (−3.6,18.5)	2.03 (−8,13.2)	13.93 (−0.3,30.3)
	≥65	1.39 (−0.4,3.3)	**2.98 (0.2,5.8)**	1.3 (−3.6,6.5)	−1.74 (−6.3,3.1)	−2.37 (−7.7,3.2)	−3.25 (−10,4)	6.09 (−0.9,13.6)	6 (−4.1,17.2)
lag1	Non-accidental	1.25 (−1.2,3.8)	0.94 (−1.3,3.2)	1.54 (−2.5,5.7)	−0.92 (−4.6,2.9)	−4.01 (−8.3,0.5)	**7.22 (1.3,13.5)**	5.29 (−0.5,11.5)	2.11 (−5.8,10.7)
	Cardiovascular	2.7 (−2.7,8.4)	**4.65 (0.5,9)**	0.4 (−6.7,8.1)	−2.32 (−8.6,4.4)	−2.88 (−11,5.9)	0.45 (−10.5,12.7)	**23.2(10.2,37.7)**	−0.08 (−14.6,16.9)
	Respiratory	3.84 (−1.9,9.9)	−0.5 (−8.8,8.6)	5.98 (−9.2,23.6)	8.52 (−6.2,25.6)	3.21 (−13.2,22.8)	15.62 (−6,42.2)	6.79 (−14.6,33.6)	2.04 (−24.5,37.9)
	Male	2.63 (−1.1,6.5)	−0.13 (−3,2.8)	3.07 (−2.2,8.6)	0.1 (−4.9,5.3)	−4.27 (−9.9,1.8)	**8.26 (0.3,16.8)**	**11.63 (3.3,20.6)**	6.79 (−4.4,19.3)
	Female	1.28 (−0.9,3.5)	**3.81 (0.5,7.2)**	−0.45 (−6,5.5)	−1.83 (−7.2,3.8)	−2.99 (−9.4,3.9)	7.1 (−1.5,16.4)	−1.64 (−9.6,7.1)	−3.98 (−14.9,8.4)
	<65	0.83 (−1.6,3.3)	0.91 (−2.6,4.5)	0.29 (−6.2,7.2)	−2.01 (−8,4.3)	−2.12 (−9.4,5.8)	6.46 (−3.9,18)	7.14 (−3.2,18.6)	4.18 (−9.1,19.5)
	≥65	1.46 (−0.4,3.3)	1.66 (−1.1,4.5)	2.44 (−2.5,7.6)	0.8 (−3.8,5.7)	−4.82 (−10,0.7)	**7.38 (0.2,15)**	4.15 (−2.8,11.6)	0.54 (−9.2,11.3)
lag2	Non-accidental	0.83 (−0.6,2.3)	1.53 (−0.7,3.8)	−0.28 (−4.2,3.8)	−1.49 (−5.2,2.3)	0.56 (−3.8,5.1)	−0.45 (−6.1,5.5)	5.44 (−0.4,11.6)	0.98 (−6.9,9.5)
	Cardiovascular	2.73 (−1.9,7.6)	3.26 (−0.9,7.6)	0.54 (−6.6,8.2)	−3.66 (−9.9,3)	−0.93 (−9.1,8)	0.63 (−10.3,12.8)	**19.8 (7,34.1)**	10.13 (−5.3,28.1)
	Respiratory	4.12 (−1.6,10.2)	4.07 (−4.5,13.4)	7.33 (−8,25.2)	4.76 (−9.6,21.3)	3.08 (−13.3,22.6)	6.11 (−14.4,31.5)	−7.41 (−27,17.8)	8.35 (−19.3,45.5)
	Male	**2.4 (0.4,4.4)**	**3.32 (0.4,6.3)**	0.71 (−4.5,6.2)	2.3 (−2.7,7.5)	0.94 (−4.9,7.1)	−2.72 (−10.1,5.3)	7.9 (−0.2,16.7)	1.09 (−9.7,13.1)
	Female	−0.03 (−2.2,2.2)	1.24 (−2,4.6)	−0.81 (−6.4,5.1)	**−5.8 (-10.9,-0.3)**	0.23 (−6.3,7.2)	3.2 (−5.2,12.3)	2.47 (−5.7,11.4)	−0.01 (−11.2,12.6)
	<65	**2.49 (0.1,5)**	**4.71 (1.2,8.4)**	−1.03 (−7.4,5.8)	1.12 (−4.9,7.5)	0.36 (−7.1,8.4)	−1.51 (−11.4,9.5)	6.86 (−3.5,18.3)	−4.42 (−17,10)
	≥65	0.57 (−1.2,2.4)	0.66 (−2.1,3.5)	0.56 (−4.3,5.7)	−1.98 (−6.5,2.8)	0.58 (−4.8,6.2)	−0.06 (−6.9,7.3)	4.44 (−2.5,11.9)	4.11 (−5.8,15.1)
lag3	Non-accidental	**1.57 (0.1,3.1)**	1.64 (−0.6,3.9)	0.29 (−3.7,4.4)	−0.63 (−4.3,3.2)	1.67 (−2.7,6.3)	3.98 (−1.8,10.1)	3.8 (−2,9.9)	6.52 (−1.6,15.3)
	Cardiovascular	1.7 (−1,4.5)	0.36 (−3.7,4.6)	−3.11 (−10.1,4.4)	3.02 (−3.5,10)	2.28 (−6,11.3)	5.65 (−5.5,18.2)	11.05 (−1.1,24.7)	9.7 (−5.8,27.7)
	Respiratory	5.51 (−0.3,11.6)	5.25 (−3.3,14.5)	7.97 (−7.4,25.9)	2.62 (−11.5,18.9)	9.78 (−7.4,30.1)	−1.47 (−21,22.8)	6.77 (−14.9,33.9)	9.6 (−18.1,46.6)
	Male	**2.24 (0.3,4.3)**	3.65 (0.8,6.6)	1.56 (−3.7,7.1)	−0.67 (−5.6,4.5)	1.57 (−4.3,7.8)	2.19 (−5.4,10.4)	1.48 (−6.3,10)	2.18 (−8.5,14.2)
	Female	1.78 (−0.4,4)	1.23 (−2,4.5)	−0.58 (−6.2,5.4)	−0.46 (−5.8,5.2)	1.94 (−4.6,8.9)	6.23 (−2.2,15.4)	6.1 (−2.3,15.2)	11.11 (−0.8,24.4)
	<65	**2.43 (0,4.9)**	5.37 (1.8,9.1)	0.09 (−6.3,7)	−0.83 (−6.8,5.5)	−1.48 (−8.8,6.4)	−2.27 (−12.1,8.6)	0.95 (−9,12)	6.04 (−7.3,21.3)
	≥65	1.69 (−0.1,3.5)	0.43 (−2.3,3.2)	0.86 (−4,6)	0.57 (−4,5.4)	3.17 (−2.3,8.9)	6.16 (−0.9,13.7)	4.63 (−2.3,12.1)	6.75 (−3.3,17.8)

Bold letters mean that the p-values are less than 0.05.
[a] Result of Meta-analysis for Asian dust effects in seven metropolitan cities, Korea during 2001−2009.

It has been reported that dust particles and microorganisms of dust storms may be factors which cause adverse health effects (Zanobetti et al., 2000; Kim et al., 2003; Lee et al., 2009; He et al., 2010). Particles cause inflammatory reaction by affecting the bronchus and damage the defense mechanisms of the lungs. Furthermore, particles increase production of immune antibodies, change airways responsiveness to antigens, and as a result can cause people's susceptibility to disease (Zanobetti et al., 2000; Lei et al., 2004). Effects of particles depend on the size (Kwon, 2012). Particle size is mostly divided into two, PM_{10} (particulate matter less than 10 μm in diameter) and $PM_{2.5}$ (particulate matter less than 2.5 μm in diameter). PM_{10} is also called thoracic particles, because it penetrates into the lower respiratory system. $PM_{2.5}$ can reach to the region of the lungs for the gas-exchange and is thus called respirable particles (de Longueville et al., 2013). Recently, a study reported that coarse particles ($PM_{10\text{-}2.5}$) could affect respiratory disease by reaching to bronchial passage, while fine particles ($PM_{2.5}$) could affect cardiovascular disease by reaching to the alveoli for gas-exchange (Sandstrom and Forsberg, 2008). In Korea, chemical compositions of dust particles are different by origins and transport patterns of dust storms (Lee et al., 2010; Kim et al., 2012). Usually, dust particles consist of coarse particles because it is the mineral dust constituting the soil of desert regions. However, when dust storms pass through industrial regions of Eastern China, the proportion of $PM_{2.5}$ is getting higher (Kim et al., 2012; Kwon, 2012).

We have some limitations in this study. First, we estimated pooled effects of Asian dust storms on mortality in Korea by conducting meta-analysis of seven metropolitan cities. Thus, the results where total mortality of entire Korea is analyzed may be different from our results. Second, we could not analyze the effects of dust particles by size separately, because we were not able to get $PM_{2.5}$ data for 6 metropolitan cities except Seoul. Separate analyses by particle size may have given evidence that the different dust particles by size could affect mortality by subgroups (disease, sex, and age) differently (Sandstrom and Forsberg, 2008). Finally, because of unavailability and shortage of data, we could not consider chemical compositions of dust particles and transport patterns of dust storms in our study despite the importance of these factors (Kim et al., 2012; Kwon, 2012). As a result, we could not find what specific compositions of dust storms affected mortality and how different the dust storm effects are according to transport patterns. Thus, if data is available, further studies should consider chemical compositions of dust particles and transport patterns of dust storms as well as different effect of dust particles by size.

In spite of these limitations, this study has found statistically significant effects of dust storm on mortality, where results of the studies on the association between dust storms and mortality have been inconsistent and controversial. Desertification due to climate change and industrialization of regions which dust storms pass through deepen adverse effects of dust storms globally (Prospero and Lamb, 2003; Parry et al., 2007; Kwon, 2012). In this respect, it is necessary to conduct continuous studies on dust storms and their adverse effects. Also, because dust storms mainly occur during a few days of specific seasons in Korea (Kwon et al., 2002; Lee et al., 2007), it is important to collect data of dust storms continually and consistently for estimating adverse health effects of dust storms with statistical power. Finally, our study suggested that a dust warning system could play an important role in protecting people from dust storms. Thus it is advised for a government to develop a well-established dust warning system and to let people recognize the adverse health effects of dust storms.

5. Conclusion

In this study, we used a nine-year dataset to estimate the effects of Asian dust storms on mortality, and it is thought that this period is long enough to detect statistical significance of dust storm effects. Our study found a statistically significant association between Asian dust storms and daily mortality in Korea and presented a pooled effect estimate by meta-analysis of multiple cities in a country. Also, this study found different lag effects of Asian dust storms on mortality by subgroups. The results show the possibility of the effects of a dust warning system. In a situation where previous studies on the relationship between dust storms and mortality have been inconsistent and controversial, our study suggests the evidence of dust storm effects on mortality.

Acknowledgment

This study was supported by the International Research & Development Program (#2012K1A3A1A12054839), Basic Science Research Program (#2010-0009581), Women Scientist Research Program (#2012R1A1A3005549) and Global Research Lab (#K21004000001-10A0500-00710) through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science, and Technology.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.atmosenv.2013.06.046.

References

Badarinath, K.V., Kharol, S.K., Kaskaoutis, D.G., Kambezidis, H.D., 2007. Case study of a dust storm over Hyderabad area, India: its impact on solar radiation using satellite data and ground measurements. Science of the Total Environment 384 (1–3), 316–332.

Barnett, A.G., Fraser, J.F., Munck, L., 2012. The effects of the 2009 dust storm on emergency admissions to a hospital in Brisbane, Australia. International Journal of Biometeorology 56 (4), 719–726.

Carslaw, D.C., Beevers, S.D., 2005. Estimations of road vehicle primary NO_2 exhaust emission fractions using monitoring data in London. Atmospheric Environment 39 (1), 167–177.

Chan, C.C., Chuang, K.J., Chen, W.J., Chang, W.T., Lee, C.T., Peng, C.M., 2008. Increasing cardiopulmonary emergency visits by long-range transported Asian dust storms in Taiwan. Environmental Research 106 (3), 393–400.

Chan, C.C., Ng, H.C., 2011. A case-crossover analysis of Asian dust storms and mortality in the downwind areas using 14-year data in Taipei. Science of the Total Environment 410-411, 47–52.

Chang, C.C., Lee, I.M., Tsai, S.S., Yang, C.Y., 2006. Correlation of Asian dust storm events with daily clinic visits for allergic rhinitis in Taipei, Taiwan. Journal of Toxicology and Environmental Health, Part A 69 (3), 229–235.

Chen, Y., Cai, Q., Tang, H., 2003. Dust storm as an environmental problem in north China. Environmental Management 32 (4), 413–417.

Chen, Y.S., Sheen, P.C., Chen, E.R., Liu, Y.K., Wu, T.N., Yang, C.Y., 2004. Effects of Asian dust storm events on daily mortality in Taipei, Taiwan. Environmental Research 95 (2), 151–155.

Chen, Y.S., Yang, C.Y., 2005. Effects of Asian dust storm events on daily hospital admissions for cardiovascular disease in Taipei, Taiwan. Journal of Toxicology and Environmental Health, Part A 68 (17–18), 1457–1464.

Cheng, M.F., Ho, S.C., Chiu, H.F., Wu, T.N., Chen, P.S., Yang, C.Y., 2008. Consequences of exposure to Asian dust storm events on daily pneumonia hospital admissions in Taipei, Taiwan. Journal of Toxicology and Environmental Health, Part A 71 (19), 1295–1299.

Chiu, H.F., Tiao, M.M., Ho, S.C., Kuo, H.W., Wu, T.N., Yang, C.Y., 2008. Effects of Asian dust storm events on hospital admissions for chronic obstructive pulmonary disease in Taipei, Taiwan. Inhalation Toxicology 20 (9), 777–781.

Chung, Y.S., 1992. On the observations of yellow sand (dust storms) in Korea. Atmospheric Environment, Part A 26 (15), 2743–2749. General Topics.

de Longueville, F., Ozer, P., Doumbia, S., Henry, S., 2013. Desert dust impacts on human health: an alarming worldwide reality and a need for studies in West Africa. International Journal of Biometeorology 57 (1), 1–19.

Dominici, F., McDermott, A., Zeger, S.L., Samet, J.M., 2002. On the use of generalized additive models in time-series studies of air pollution and health. American Journal of Epidemiology 156 (3), 193–203.

Goto, K., Nmor, J.C., Kurahashi, R., Minematsu, K., Yoda, T., Rakue, Y., Mizota, T., Gotoh, K., 2010. Relationship between influx of yellow dust and bronchial asthma mortality using satellite data. Scientific Research and Essays 5 (24), 4044–4052.

Guo, J., Rahn, K.A., Zhuang, G., 2004. A mechanism for the increase of pollution elements in dust storms in Beijing. Atmospheric Environment 38 (6), 855–862.

Gyan, K., Henry, W., Lacaille, S., Laloo, A., Lamsee-Ebanks, C., McKay, S., Antoine, R., Monteil, M., 2005. African dust clouds are associated with increased paediatric asthma accident and emergency admissions on the Caribbean island of Trinidad. International Journal of Biometeorology 49 (6), 371–376.

Hashizume, M., Nishiwaki, Y., Michikawa, T., Ueda, K., Onozuka, D., Yokota, K., Mine, M., Mori, A., Shimizu, A., Sugimoto, N., 2011. Effects of Asian dust events on daily mortality in Nagasaki, Japan. Epidemiology 22 (1), S130.

Hastie, T., Tibshirani, R., 1986. Generalized additive models. Statistical Science 1 (3), 297–318.

He, M., Ichinose, T., Yoshida, S., Nishikawa, M., Mori, I., Yanagisawa, R., Takano, H., Inoue, K., Sun, G., Shibamoto, T., 2010. Airborne Asian sand dust enhances murine lung eosinophilia. Inhalation Toxicology 22 (12), 1012–1025.

Holyoak, A.L., Aitken, P.J., Elcock, M.S., 2011. Australian dust storm: impact on a statewide air medical retrieval service. Air Medical Journal 30 (6), 322–327.

Hong, Y.C., Pan, X.C., Kim, S.Y., Park, K., Park, E.J., Jin, X., Yi, S.M., Kim, Y.H., Park, C.H., Song, S., 2010. Asian dust storm and pulmonary function of school children in Seoul. Science of the Total Environment 408 (4), 754–759.

Hwang, S., Cho, S., Kang, D., Kim, H., Ha, E., Kwon, H., 2003. The Asian dust events and hospital admissions with respiratory and cardiovascular disease in Seoul, Korea: Isee-249. Epidemiology 14 (5), S48.

Hwang, S.S., Cho, S.H., Kwon, H.J., 2004. Effects of the Asian dust events on mortality in the Spring of 2002, Seoul, Korea. Epidemiology 15 (4), S126.

Johnston, F., Hanigan, I., Henderson, S., Morgan, G., Bowman, D., 2011. Extreme air pollution events from bushfires and dust storms and their association with mortality in Sydney, Australia 1994–2007. Environmental Research 111 (6), 811–816.

Kanatani, K.T., Ito, I., Al-Delaimy, W.K., Adachi, Y., Mathews, W.C., Ramsdell, J.W., 2010. Desert dust exposure is associated with increased risk of asthma hospitalization in children. American Journal of Respiratory and Critical Care Medicine 182 (12), 1475–1481.

Kim, H.S., Chung, Y.S., Lee, S.G., 2012. Characteristics of aerosol types during large-scale transport of air pollution over the Yellow Sea region and at Cheongwon, Korea, in 2008. Environmental Monitoring Assessment 184 (4), 1973–1984.

Kim, Y., Kim, K., Kwak, N., Lee, K., Kweon, S., Lim, Y., 2003. Cytotoxicity of yellow sand in lung epithelial cells. Journal of Biosciences 28 (1), 77–81.

Kirchstetter, T.W., Harley, R.A., Littlejohn, D., 1996. Measurement of nitrous acid in motor vehicle exhaust. Environmental Science and Technology 30 (9), 2843–2849.

Kloor, K., 2008. Archaeology. Dust storm rising over threat to famed rock art in Utah. Science 319 (5862), 394.

Kwon, H.J., 2012. Toxicity and health effects of Asian dust: a literature review. Journal of the Korean Medical Association 55 (3), 234–242.

Kwon, H.J., Cho, S.H., 2004. The health effects of Asian dust event. Journal of the Korean Medical Association 47 (5), 465–470.

Kwon, H.J., Cho, S.H., Chun, Y., Lagarde, F., Pershagen, G., 2002. Effects of the Asian dust events on daily mortality in Seoul, Korea. Environmental Research 90 (1), 1–5.

Lee, B.K., Lee, H.K., Jun, N.Y., 2006. Analysis of regional and temporal characteristics of PM_{10} during an Asian dust episode in Korea. Chemosphere 63 (7), 1106–1115.

Lee, H., Tanaka, T., Chiba, M., Igarashi, Y., 2003. Long range transport of Asian dust from dust storms and its impact on Japan. Water, Air, and Soil Pollution: Focus 3 (2), 231–243.

Lee, J.T., Son, J.Y., Cho, Y.S., 2007. A comparison of mortality related to urban air particles between periods with Asian dust days and without Asian dust days in Seoul, Korea, 2000–2004. Environmental Research 105 (3), 409–413.

Lee, S., Choi, B., Yi, S.M., Ko, G.P., 2009. Characterization of microbial community during Asian dust events in Korea. Science of the Total Environment 407 (20), 5308–5314.

Lee, S.J., Moon, G.J., Park, S.M., Park, J.S., Ahn, J.Y., Kim, J.S., 2010. Chemical characteristics of ambient fine aerosols in Seoul (2009). In: Proceeding of the 50th Meeting of KOSAE.

Lei, Y.C., Chan, C.C., Wang, P.Y., Lee, C.T., Cheng, T.J., 2004. Effects of Asian dust event particles on inflammation markers in peripheral blood and bronchoalveolar lavage in pulmonary hypertensive rats. Environmental Research 95 (1), 71–76.

Mallone, S., Stafoggia, M., Faustini, A., Gobbi, S., Forastiere, F., Perucci, C.A., 2009. Effect of Saharan dust on the association between particulate matter and daily mortality in Rome, Italy. Epidemiology 20 (6), S66.

Meng, Z., Lu, B., 2007. Dust events as a risk factor for daily hospitalization for respiratory and cardiovascular diseases in Minqin, China. Atmospheric Environment 41 (33), 7048–7058.

Meng, Z., Zhang, Q., 2006. Oxidative damage of dust storm fine particles instillation on lungs, hearts and livers of rats. Environmental Toxicology and Pharmacology 22 (3), 277–282.

Meng, Z., Zhang, Q., 2007. Damage effects of dust storm PM2.5 on DNA in alveolar macrophages and lung cells of rats. Food and Chemical Toxicology 45 (8), 1368–1374.

Middleton, N., Yiallouros, P., Kleanthous, S., Kolokotroni, O., Schwartz, J., Dockery, D.W., Demokritou, P., Koutrakis, P., 2008. A 10-year time-series analysis of respiratory and cardiovascular morbidity in Nicosia, Cyprus: the effect of short-term changes in air pollution and dust storms. Environmental Health 7 (39), 1–16.

Monteil, M.A., 2008. Saharan dust clouds and human health in the English-speaking Caribbean: what we know and don't know. Environmental Geochemistry and Health 30 (4), 339–343.

Nakai, S., Nitta, H., Maeda, K., 1995. Respiratory health associated with exposure to automobile exhaust. II. Personal NO_2 exposure levels according to distance from the roadside. Journal of Exposure Analysis and Environmental Epidemiology 5 (2), 125–136.

Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E., 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Summary for Policymakers. Cambridge University Press, Cambridge, U.K., pp. 7–22

Prospero, J.M., Lamb, P.J., 2003. African droughts and dust transport to the Caribbean: climate change implications. Science 302 (5647), 1024–1027.

Sajani, S.Z., Miglio, R., Bonasoni, P., Cristofanelli, P., Marinoni, A., Sartini, C., Goldoni, C.A., De Girolamo, G., Lauriola, P., 2011. Saharan dust and daily mortality in Emilia-Romagna (Italy). Occupational and Environmental Medicine 68 (6), 446–451.

Samoli, E., Kougea, E., Kassomenos, P., Analitis, A., Katsouyanni, K., 2011. Does the presence of desert dust modify the effect of PM_{10} on mortality in Athens, Greece? Science of the Total Environment 409 (11), 2049–2054.

Sandstrom, T., Forsberg, B., 2008. Desert dust: an unrecognized source of dangerous air pollution? Epidemiology 19 (6), 808–809.

Tam, W.W., Wong, T.W., Wong, A.H., Hui, D.S., 2012. Effect of dust storm events on daily emergency admissions for respiratory diseases. Respirology 17 (1), 143–148.

Taylor, D.A., 2002. Dust in the wind. Environmental Health Perspectives 1101 (2), A80–A87.

Uno, I., Eguchi, K., Yumimoto, K., Takemura, T., Shimizu, A., Uematsu, M., Liu, Z., Wang, Z., Hara, Y., Sugimoto, N., 2009. Asian dust transported one full circuit around the globe. Nature Geoscience 2 (8), 557–560.

Watanabe, M., Yamasaki, A., Burioka, N., Kurai, J., Yoneda, K., Yoshida, A., Igishi, T., Fukuoka, Y., Nakamoto, M., Takeuchi, H., 2011. Correlation between Asian dust storms and worsening asthma in western Japan. Allergology International 60 (3), 267–275.

Wei, A., Meng, Z., 2006a. Evaluation of micronucleus induction of sand dust storm fine particles (PM(2.5)) in human blood lymphocytes. Environmental Toxicology and Pharmacology 22 (3), 292–297.

Wei, A., Meng, Z., 2006b. Induction of chromosome aberrations in cultured human lymphocytes treated with sand dust storm fine particles (PM2.5). Toxicology Letters 166 (1), 37–43.

Yang, C.Y., Chen, Y.S., Chiu, H.F., Goggins, W.B., 2005. Effects of Asian dust storm events on daily stroke admissions in Taipei, Taiwan. Environmental Research 99 (1), 79–84.

Yang, C.Y., Cheng, M.H., Chen, C.C., 2009. Effects of Asian dust storm events on hospital admissions for congestive heart failure in Taipei, Taiwan. Journal of Toxicology and Environmental Health, Part A 72 (5), 324–328.

Yoo, Y., Choung, J.T., Yu, J., Kim, D.K., Koh, Y.Y., 2008. Acute effects of Asian dust events on respiratory symptoms and peak expiratory flow in children with mild asthma. Journal of Korean Medical Science 23 (1), 66–71.

Zanobetti, A., Schwartz, J., Gold, D., 2000. Are there sensitive subgroups for the effects of airborne particles? Environmental Health Perspectives 108 (9), 841–845.