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Effects of Asian dust events on daily asthma patients in Seoul, Korea

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ABSTRACT: East Asia, including the Korean peninsula, is affected by dust storms originating from the deserts of Mongolia and China, especially in spring. These are called Asian dust storm (ADS) events. ADS events frequently generate ambient dust particles less than 10 μm in diameter. Particles of this size are known to be associated with adverse health effects. The aim of this study is to investigate the possible adverse effects of ADS on the asthma symptoms of residents of Seoul, South Korea, during the period 2005–2008. A paired t-test was used to compare daily medical treatment counts for asthma disease on ADS events with those on the comparison days. 'Comparison days' is defined as the 7 days before and after the ADS episodes, referred to as index days in this study. The estimated percentage increase in the rate of asthma treatments after the ADS event, using 4–6 day moving means, was about 18%. This shows a statistically significant association between ADS events and asthma treatment counts 4–6 days after the ADS event. It was also found that the percentage increase in asthma treatments on index days with high levels of PM_{10} concentration was about 22% ($P < 0.05$) in cases with a 6 day lag. This study generates evidence that ADS events are significantly associated with asthma symptoms and that increased PM_{10} levels may aggravate asthma disease.

KEY WORDS Asian dust storms; asthma; PM_{10} concentration; daily clinic visit; paired t-test

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1. Introduction

Asian dust refers to the small sand and dust particles drifting in the air and travelling long distances with the upper winds from arid regions in northern China and Mongolia before gradually falling back on to land. Such large-scale movement of clouds of sand primarily influences the eastern Asia regions, but they can travel as far as the western regions of the U.S. and Canada (McKendry *et al*., 2001). The Asian dust phenomenon has been recorded in a number of historical records of Korea since the second century (Chun *et al*., 2008), and Asian dust storms (ADSs) lasting over 10 days have occurred every year since 2000, except in 2003 and 2004 (Korea Meteorological Administration (KMA), 2010).

ADS events are most commonly observed in Korea and Japan under a high pressure system in association with strong surface winds, which are often excited by the passage of cold fronts, and baroclinic instability at the 1.5 km level (Hayasaki *et al*., 2006; Yasunari and Yamazaki, 2009). Chun *et al*. (2001) showed that meteorological conditions for ADSs, mainly characterized by periodical alternation between synoptic scale high and low pressure systems, frequently occurs in spring in East Asia. Climatologically, the Gobi Desert of Mongolia and the Taklamakan Desert of northwestern China, known as major sources of ADS, provide a favourable environments for the occurrences of ADS events and subsequent dust transport across East Asia (Yu *et al*., 2010). The 3 day back trajectories of ADSs arriving at Seoul on an ADS day (30 May 2008) are shown in Figure 1, demonstrating that the ADS event originated from Mongolia and China and crossed the Yellow Sea (Jeon *et al*., 2011).

With increasing concerns regarding the influence of Asian dust on human health, there have recently been a large number of studies performed on this issue. According to Donaldson and MacNee (1998), the effects of particulate matters on health are mainly related to the size and chemical composition of the particle. According to the findings of several studies, there is a dramatic increase in the concentration of coarse particles (between 2.5 and 10 μm in diameter) compared to fine particles (aerodynamic diameters equal to or less than 2.5 μm) on the days of ADS events. This is associated with high wind speed, which plays a role in decreasing the concentration of fine particles and other combustion-related pollutants. Thus, the PM_{10} levels increase greatly above the normal levels caused by the local conditions (Husar *et al*., 2001). Studies considering the nature of Asian dust have investigated the effects of ADSs on mortality (Kwon *et al*., 2002; Chen *et al*., 2004; Lee *et al*., 2007), respiratory symptoms (Hwang *et al*., 2003; Lei *et al*., 2004; Park *et al*., 2005; Hong *et al*., 2010), cardiovascular diseases (Meng and Lu, 2007) and stroke (Yang *et al*., 2005). Studies performed to date have analysed the frequencies of diseases and deaths arising from the occurrence of ADSs, but there have not been any studies analysing the frequency of onset of diseases caused by the variation in the PM_{10} concentration. Thus, the purpose of this study is to not only analyse the effects of ADS itself but also the effects of the PM_{10} concentrations on the days of the ADS event on the occurrence of asthma, a respiratory disease, among the residents of Seoul from 2005 to 2008. Also, the analysis of the PM_{10} concentrations was performed by grouping the 24 h mean concentrations used by the majority of previous researches separately from the 8 h mean concentrations between the hours of 1000–1800 LST (LST = UTC + 7 h) during which people are actually active outdoors.

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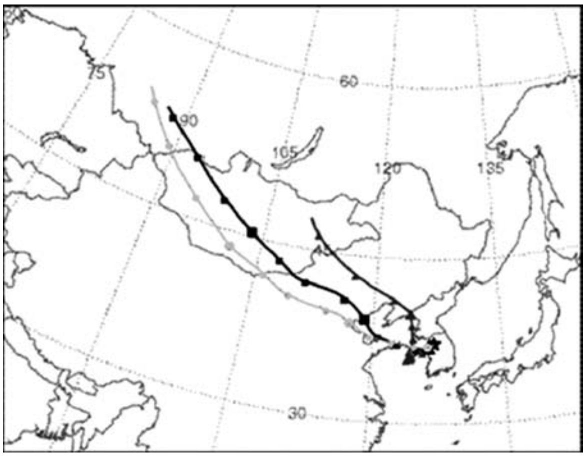

Figure 1. Three-day backward trajectories of ADS arriving at Seoul on a sampling ADS day (source: Jeon *et al*., 2011).

2. Material and methods

2.1. Area of study and data

This study focused on the specific region of Seoul, the capital city of South Korea, which is located in the centre of the Korean peninsula and has a temperate continental climate with a warm summer. Seoul has a population of approximately 10.5 million and an area of 605 km^2. The population of Seoul accounts for one-fifth of the total population of South Korea, while the area of Seoul is equal to 0.6% of South Korean territory.

The data on the number of medical services provided to asthma patients at all hospitals and clinics in the Seoul region from 2005 to 2008 were obtained from the Health Insurance Review and Assessment Service (HIRAS). The HIRAS, a health care organization affiliated with the government, is primarily responsible for reviewing medical bills and has a computerized record of the daily medical records from all hospitals and clinics. The data associated with the air pollution levels in the same periods and regions as the medical data were provided by the National Institute of Environmental Research. The data consisted of the hourly measurements of the carbon monoxide, nitrogen dioxide, sulphur dioxide, ozone and PM_{10} concentrations, which were compiled from 27 monitoring stations distributed evenly throughout Seoul.

The hourly measurements of the five air pollutants were converted into 24 h and 8 h (1000–1800) mean concentrations, which were used as the basic materials of the analysis. In addition, the information associated with the occurrence of ADSs in the same periods and regions was obtained from the Korea Meteorological Administration. According to the data, the ADS phenomenon was observed in the Seoul region for a total of 40 days from 2005 to 2008 (Table 1).

Table 1. Asian dust storm days in Seoul, Korea, 2005–2008.

Year	Date
2005	29 March, 7 April, 10 April, 14–15 April, 20–22 April, 28–29 April, 6–7 November
2006	11 March, 13 March, 28 March, 7–9 April, 18 April, 23–24 April, 30 April, 1 May
2007	14 February, 6 March, 27–28 March, 31 March, 1–2 April, 8–9 May, 25–26 May, 29 December
2008	12 February, 2–3 March, 16 March, 3–4 April, 30–31 May

2.2. Analysis method

In general, studies conducted to investigate the relationship between air pollution and diseases must have a control for patterns of the day of the week, seasons and human behaviour according to the purpose of the study. In order to control confounding by long-term time series patterns, day of the week and seasonal trends, this study employed the concept of index days and symmetrical comparison days (Bateson and Schwartz, 1999; Chen *et al*., 2004; Yang *et al*., 2005). Index days correspond to the days when the ADS events actually occurred, while 7 days before and after the ADS occurrence day (the index day) were designated as comparison days.

In addition, in cases of two or more consecutive days of ADS, the harvesting effect was taken into consideration; individuals who are vulnerable to diseases brought on by ADS will visit the hospital on one of the consecutive ADS days and, thus, there is a decrease in the number of visits to the hospital on the following days. This phenomenon may decrease the accuracy of the estimation and analysis of the correlation between ADSs and related diseases (Yang *et al*., 2005). Thus, for cases where an ADS occurred for two or more consecutive days, only the last day of such an event was considered as the index day. However, if the difference between the PM_{10} concentrations of the days in question was over 110 $\mu g\ m^{-3}$, all the days of the ADS period were considered as the index days for analysis. For instance, the 8 h mean PM_{10} concentrations on 1 April 2007 and the following day are 583.89 and 59.57 $\mu g\ m^{-3}$, respectively, and thus have a difference of over 110 $\mu g\ m^{-3}$. Both days were designated as index days in spite of the fact that they are consecutive days of ADS events. The 8 and 9 May 2007 and 30 and 31 May 2008, during which there was a continuous occurrence of ADSs, were also designated as the index days for the same reason.

Paired t-tests were carried out on the mean numbers of medical services provided to asthma patients on the index and comparison days for analysis. If an ADS occurred on one of the two comparison days only the number of medical services provided on the other comparison day was used as data for the paired t-test. If an ADS occurred on both comparison days of an index day, they were excluded from the analysis data. Thus, 3 days from 20 to 22 April 2005 satisfying this criterion were excluded from the data. The index days and comparison days selected according to these criteria are shown in Table 2.

The effects of ADSs on human health tend to appear days later and asthma is not a type of disease that must be treated immediately upon onset, such as stroke or heart diseases. Therefore, a patient's visit to the hospital or clinic may take place a few days after the ADS event. In order to reflect this phenomenon, a moving mean of the number of daily medical services provided from the day of ADS occurrence to the corresponding lag day was used in the paired t-test. For example, in order to observe the lag effect between the day of ADS occurrence and 3 days after the occurrence, a 4 day moving mean of the number of medical services provided on the day of ADS occurrence, i.e., the index day, and the next 3 days as well as a 4 day moving mean of the number of medical services provided on the comparison day and the next 3 days were used in the paired t-test for analysis.

Lastly, in order to investigate the effects of the intensity of Asian dust, i.e., the PM_{10} concentration, the index days were categorized into a group with high mean PM_{10} concentrations and a group with low mean PM_{10} concentrations. The groups were classified based on whether their PM_{10} concentration

Table 2. Asian dust storm days selected for the analysis in this study.

Year	Date	24 h PM_{10} (μg m^{-3})		8 h PM_{10} (μg m^{-3})	
		Mean	Max	Mean	Max
2005	29 March	103.1	234	120.3	223
	7 April	109.0	197	158.5	197
	10 April	74.0	252	41.6	112
	15 April	89.8	136	104.7	118
	29 April	118.8	165	115.4	147
	7 November	90.6	150	66.9	96
2006	11 March	173.2	337	242.3	337
	13 March	131.4	326	183.9	323
	28 March	94.2	168	110.0	168
	9 April	344.2	1080	195.3	274
	18 April	102.7	144	95.4	135
	24 April	177.3	257	226.1	257
	1 May	150.2	240	122.3	189
2007	14 February	80.3	152	119.6	152
	6 March	98.2	206	105.4	200
	28 March	175.3	259	205.8	259
	1–2 April	380.0	851	583.9	851
	8–9 May	111.6	336	220.0	336
	26 May	220.2	387	149.3	238
	29 December	252.0	425	378.0	425
2008	12 February	135.3	193	158.3	193
	3 March	63.9	98	74.4	98
	16 March	120.3	173	145.7	171
	4 April	97.9	136	77.3	118
	30–31 May	261.0	687	429.0	687

8 h based PM_{10} concentration levels were obtained in the period 1000–1800.

level was above or below the mean PM_{10} concentration of 110 μg m^{-3}, which is twice the mean PM_{10} concentration level reported in the Seoul region during 2005–2008. The groups were separately determined for the cases of 24 h and 8 h, and a paired t-test was performed for each group.

3. Results and discussion

3.1. Comparison of air pollutants level

Table 3 shows the mean values and 95% confidence intervals of the concentrations of the air pollutants in the Seoul region on the index days and comparison days from 2005 to 2008. The summary statistics of the daily concentrations of the variables in Table 3 were obtained and compared separately for 24 h and 8 h. The results of the paired t-test showed that the mean PM_{10} and NO_2 concentrations were statistically significant in the cases of 24 h and 8 h. In contrast, the mean concentrations of other air pollutants (CO, O_3, SO_2) showed slightly different results depending on whether the calculation of the mean values was based on a 24 h or 8 h period. The mean concentrations of CO and SO_2 were higher on the comparison days than the index days and the 24 h mean concentration of CO and the 8 h mean concentration of SO_2 were statistically significant. As for O_3, the 24 h mean concentration was observed to be slightly higher on the index days than the comparison days but the 8 h mean concentrations of these days were similar.

There have been numerous studies conducted to analyse the concentrations of air pollutants, including PM_{10}, on ADS events (Kwon *et al*., 2002; Chen *et al*., 2004; Lei *et al*., 2004; Park *et al*., 2005; Yang *et al*., 2005; Lee *et al*., 2007). However, it is difficult to find research results that are consistent with each other when the PM concentration is excluded. The results of the analysis of air pollutant concentrations obtained in the present study demonstrate a similar pattern with the research findings of Lei *et al*. (2004) and Park *et al*. (2005): in particular, the SO_2, NO_2 and CO concentrations were found to be higher on the comparison days compared to the index days. This is thought to be caused by the effect of the high surface wind speed accompanying ADSs to reduce the level of fine particles and other combustion-related pollutants (Schwartz *et al*., 1999; Chun *et al*., 2001). The combustion-related pollutants (SO_2, NO_2, CO) and PM_{10} are known to have a significant association with asthma symptoms (Schwartz, 1995; Seaton *et al*., 1995; Tattersfield, 1996; WHO, 2005). Unlike PM_{10}, however, the fact that their concentrations are lower on the index days compared to the comparison days may have a counter result in performing an analysis based on the PM_{10} concentration. However, because the concentrations of the air pollutants measured in this study do not exceed those of the WHO guidelines (WHO, 2005), the effects of SO_2, NO_2 and CO on asthma were not analysed additionally. The concentrations of O_3 calculated based on a 24 h period and an 8 h period showed no statistically significant difference between the index days and the comparison days and, thus, O_3 was not believed to be a factor in the increase of asthma patients on the day of ADS events and was excluded from the analysis.

3.2. Annual pattern of asthma disease

In Seoul, asthma disease occurred with a monthly clinical attack rate of 1.7% during the period from 2005 to 2008. The relationship between ADS and asthma attack rate can be clarified through the annual pattern of the occurrences of asthma disease and ADS shown in Figure 2. A great proportion of ADS during the 4 years, i.e. 30 out of 34, occurred in March to May. On the other hand, asthma attacks had two major peaks around March to May and November to December. A clear relationship between ADS and asthma attack can be seen from the peak around March to May, as the greater part of the ADS days in Table 2, which are used for this study, correspond to the peak. The other peak, around November to December, is known to

Table 3. Daily means of environmental variables on Asian dust days (index days) and comparison days in Seoul, Korea, 2005–2008.

	24 h mean			8 h mean		
	Index days	Comparison days	p-value	Index days	Comparison days	p-value
PM_{10} (μg m^{-3})	143.38 ± 31.67	77.73 ± 8.85	0.0004	165.59 ± 47.13	76.14 ± 9.66	0.0006
SO_2 (ppb)	5.67 ± 0.79	6.75 ± 0.82	0.0522	5.88 ± 0.77	7.46 ± 1.01	0.0254
O_3 (ppb)	25.32 ± 4.28	21.34 ± 3.06	0.0612	31.33 ± 5.00	31.96 ± 4.46	0.7955
NO_2 (ppb)	35.77 ± 3.75	47.72 ± 5.25	0.0022	31.83 ± 3.93	40.03 ± 4.91	0.0204
CO (ppm)	0.52 ± 0.07	0.66 ± 0.12	0.0322	0.48 ± 0.07	0.56 ± 0.09	0.1441

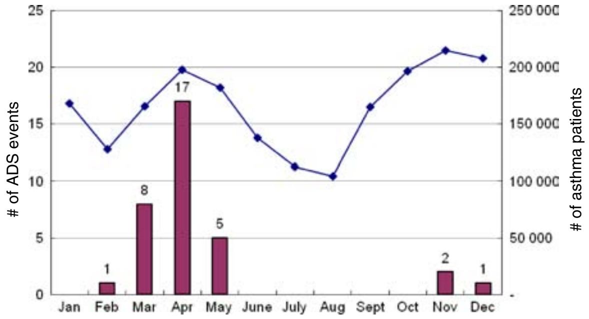

Figure 2. Pattern of ADS events and asthma attacks during the study period. Line graph shows the average number of asthma patients and bar chart indicates the total number of ADS events for each month during 2005–2008. This figure is available in colour online at wileyonlinelibrary.com/journal/met

be caused mainly by low temperature (Frei, 1995) and is not considered in this study.

3.3. Analysis results of the relationship between ADS event and asthma disease

Table 4 shows the mean values, 95% confidence intervals and the p-values obtained from the paired t-tests for the multiday moving mean values of the number of asthma patients' hospital or clinic visits on the index and comparison days. The percentage increase of medical services provided for asthma on the comparison days compared to the index days according to the day lags showed that there was a 3.79% increase in the number of medical services on the day of ADS occurrence (0 day lag) and that there was continuous increase along with the day lags with an increase of approximately 18% on days 4–6 after the ADS event.

The response lag time used to analyse the short-term effects of air pollutants on health is commonly less than 4 days (Katsouyanni *et al*., 1997; Chen *et al*., 2004; Kwon *et al*., 2002; Yang *et al*., 2005; Lee *et al*., 2007; Leung *et al*., 2008). However, Meng and Lu (2007) analysed their data by considering up to a 6 day lag and demonstrated that the effects of Asian dust on the symptoms of pneumonia are statistically significant even at 6 day lag. Because asthma also belongs to the category of respiratory diseases, just as pneumonia, data obtained up to the 6 day lag period were analysed. The mean number of daily medical services provided for asthma on the index days was higher than that of the comparison days, regardless of the day lags. There was a negative correlation between the day lags and the p-values, and the mean numbers of medical services in between the 4 day lag and 6 day lag were statistically significant at a significance level of 5%. Therefore, the mean daily number of patients who visited the hospital or clinic for asthma treatment 4, 5 or 6 days after the day of an ADS event, i.e., the index day, was higher than the mean daily number of asthma patients on the same day lags from the comparison days and this was statistically significant. This indicates that there is a clear lagged effect of the exposure 4 days after the index day, and it reflects the nature of asthma as it is different from the findings that there is the greatest lagged effect of the exposure on death at 2 day lag (Kwon *et al*., 2002; Chen *et al*., 2004) and that there is the greatest lagged effect of the exposure on stroke at 3 day lag. In other words, considering the seriousness of the diseases, stroke or death requires the case to be reported to a hospital or the patient to be taken to the hospital immediately and, thus, such cases are recorded immediately upon their occurrence. However, there may be a delay in the onset of asthma symptoms caused by Asian dust and patients may delay their visit to the hospital if their symptoms are not too serious depending on their personal situations. Thus, it could be said that the lag effect of the exposure on asthma may appear 1–2 days later compared to death or stroke due to its nature.

Table 5 shows the results of the comparative analysis of the numbers of medical services provided in the groups with PM_{10} concentration levels that fall below or above 110 μg m^{-3}. When the PM_{10} concentration was calculated based on the 24 h mean value, which has been commonly used in previous studies, the numbers of medical services provided on all day lags were slightly higher in the group with $PM_{10} > 110$ μg m^{-3} compared to the group with $PM_{10} < 110$ μg m^{-3}, but the difference was not significant. On the other hand, when the PM_{10} concentration was calculated based on an 8 h mean concentration measured from 1000 to 1800, during which there are frequent outdoor activities, the mean numbers of medical services on the day of an ADS and 1 day lag were slightly higher in the group with $PM_{10} < 110$ μg m^{-3} compared to the group with $PM_{10} > 110$ μg m^{-3}. However, starting from the 2 day lag, the number of medical services increased in the group with $PM_{10} > 110$ μg m^{-3} and this trend became more noticeable as the day lags passed with a statistically significant difference shown at 6 day lag.

Table 6 shows the results of the paired t-test on the moving mean values of the number of asthma patients on the index and comparison days for each of the sub-groups, which were categorized based on whether their 24 and 8 h PM_{10} concentrations fell below or above 110 μg m^{-3}. In the group with a 24 h mean $PM_{10} < 110$ μg m^{-3}, the number of asthma patients on the index days was higher than the comparison days by as much as 12.67% (at 3 day lag). In the group with a 24 h mean $PM_{10} > 110$ μg m^{-3}, the number of asthma patients on the index days was higher compared to the comparison days by as much as 28.27% (at 6 day lag), which was statistically significant. When the PM_{10} concentrations were calculated based on the 8 h mean, the increase in the number of asthma patients was highest at 1 day lag with a 24.83% increase in the group with $PM_{10} < 110$ μg m^{-3}. In the group with an 8 h mean $PM_{10} > 110$ μg m^{-3}, there were 23.30 and 26.85% increases at 5 and 6 day lags, respectively, which were statistically significant.

In cases of high PM_{10} concentration levels, the p-values of the paired t-test for each day lag show similar patterns of lag effect to those identified for all days of the ADS occurrence regardless of PM_{10} level. In other words, the lag effect of the exposure increased along with the day lag, and there was a significant correlation between the ADS events and the number of asthma patients with the 5 and 6 day lag effect. However, in cases of high PM_{10} level based on a 24 h period, the p-value at 5 day lag was 0.0522, which could be considered statistically significant despite the fact that it is higher than 0.05. On the other hand, when the PM_{10} levels were low, there were no day lags that showed a significant correlation. However, different patterns were shown depending on whether the mean PM_{10} concentration was calculated based on a 24 h period or an 8 h period. That is, when the 24 h mean PM_{10} level was low, the p-values for all day lags showed a pattern of being higher than the days when the PM_{10} levels were higher. However, when the PM_{10} level was calculated based on an 8 h period, the p-value patterns on the days with low PM_{10} levels showed an

Table 4. Number of asthma patients on Asian dust days and comparison days by various lags.

(a)

	The same day	1 day lag	2 day lag
Index days	6837.89 ± 2348.43	6434.77 ± 1714.96	6755.37 ± 1457.30
Comparison days	6588.45 ± 1571.19	6136.97 ± 1027.33	6084.91 ± 708.31
% increase (%)	3.79	4.85	11.02
p-value	0.4078	0.3588	0.1692

(b)

3 day lag	4 day lag	5 day lag	6 day lag
6780.08 ± 1295.79	6578.37 ± 1176.76	6549.01 ± 1037.22	6596.93 ± 1037.22
5872.47 ± 676.92	5572.68 ± 578.27	5561.28 ± 540.83	5582.01 ± 540.83
15.46	18.05	17.76	18.18
0.0645	0.0322	0.0264	0.0152

Table 5. Number of asthma patients on Asian dust days with $PM_{10} > 110$ μg m^{-3} and those with $PM_{10} < 110$ μg m^{-3} by various lags.

(a)

	The same day	1 day lag	2 day lag
24 h mean			
$PM_{10} > 110$	7308.07 ± 3159.30	6949.57 ± 2205.56	7325.07 ± 1880.16
$PM_{10} < 110$	6367.71 ± 1397.48	5919.96 ± 1166.24	6185.67 ± 972.28
% increase (%)	14.77	17.39	18.42
p-value	0.3453	0.2748	0.2177
8 h mean			
$PM_{10} > 110$	6704.11 ± 2767.49	6386.06 ± 1977.41	6834.13 ± 1718.72
$PM_{10} < 110$	7078.70 ± 1457.06	6495.65 ± 1224.96	6613.60 ± 899.53
% increase (%)	−5.29	−1.69	3.33
p-value	0.4284	0.4723	0.432

(b)

3 day lag	4 day lag	5 day lag	6 day lag
6988.25 ± 1598.30	7066.17 ± 1452.14	6865.11 ± 1197.49	6974.55 ± 1017.98
6571.91 ± 996.87	6090.57 ± 875.55	6232.90 ± 891.08	6219.31 ± 843.56
6.34	16.02	10.14	12.14
0.3745	0.2035	0.2712	0.2067
7007.58 ± 1512.12	6858.99 ± 1357.22	7008.93 ± 1209.05	7055.81 ± 1045.07
6370.58 ± 832.31	6073.26 ± 789.52	5721.15 ± 557.76	5770.94 ± 583.87
10.00	12.94	22.51	22.26
0.2906	0.2294	0.0736	0.0485

opposite pattern from the days with high PM_{10} levels, i.e. there was a decrease in the lag effect of the exposure as the lag days passed. To summarize, there was a clear lag effect and increase in the number of asthma patients on the days with high PM_{10} concentrations regardless of the time period the measurement was based on. The increase in the number of asthma patients on the days with low PM_{10} levels was minimal and it was determined that the pattern of the lag effect was different according to the time period the calculation of the mean PM_{10} level was based on. On days when the mean PM_{10} concentration based on the 8 h period, during which outdoor activities are most frequent, was below 110 μg m^{-3}, there were patterns of a decrease in the lag effect and an increase in the number of asthma patients shortly after the occurrence of an ADS, even though they were not statistically significant. On the other hand, on the days of 24 h $PM_{10} < 110$ μg m^{-3} there was actually a decrease in the number of asthma patients immediately after the occurrence of an ADS. These patterns were analysed in detail in terms of the increase in the percentage of medical services on the index days compared to the comparison days, shown in Tables 4 and 6, and it was found that the percentage increase of the group with a 24 h $PM_{10} < 110$ μg m^{-3} was lower in all day lags compared to the total percentage increase (Table 4) and that the percentage increase of the group with a 24 h $PM_{10} > 110$ μg m^{-3} was higher in all day lags compared to the total percentage increase. In contrast, for the group with an 8 h $PM_{10} < 110$ μg m^{-3}, the percentage increase in the medical services on the index days was higher than the total percentage increase up to a 3 day lag and was lower than the total percentage increase from 4 day lag and onwards,

Table 6. Number of asthma patients on Asian dust days and comparison days in groups with $PM_{10} > 110$ μg m^{-3} and with $PM_{10} < 110$ μg m^{-3} by various lags.

(a)

	The same day	1 day lag	2 day lag
24 h $PM_{10} < 110$			
Index days	6367.71 ± 2032.26	5919.96 ± 1708.15	6185.67 ± 1419.26
Comparison days	6760.14 ± 2127.06	6064.98 ± 1582.99	5955.83 ± 911.39
% increase (%)	−5.81	−2.39	3.86
p-value	0.6388	0.5599	0.3801
24 h $PM_{10} > 110$			
Index days	7308.07 ± 4594.35	6949.57 ± 3230.39	7325.07 ± 2744.50
Comparison days	6416.75 ± 2611.95	6208.96 ± 1533.12	6213.99 ± 1211.50
% increase (%)	13.89	11.93	17.88
p-value	0.3191	0.2971	0.1818
8 h $PM_{10} < 110$			
Index days	7078.70 ± 2683.21	6522.45 ± 2230.63	6613.60 ± 1656.52
Comparison days	5926.75 ± 2457.05	5225.25 ± 1392.88	5598.30 ± 930.60
% increase (%)	19.44	24.83	18.14
p-value	0.1577	0.0808	0.0988
8 h $PM_{10} > 110$			
Index days	6704.11 ± 3542.83	6386.06 ± 2463.88	6834.13 ± 2200.23
Comparison days	6956.06 ± 2192.02	6643.49 ± 1439.61	6355.25 ± 1017.55
% increase (%)	−3.62	−3.87	7.54
p-value	0.4362	0.4145	0.3196

(b)

3 day lag	4 day lag	5 day lag	6 day lag
6571.91 ± 1468.59	6090.57 ± 1286.29	6232.90 ± 1319.08	6219.31 ± 1251.38
5832.68 ± 1044.89	5436.75 ± 824.06	5558.15 ± 830.53	5726.83 ± 716.56
12.67	12.03	12.14	8.60
0.1488	0.1492	0.1575	0.2040
6988.25 ± 2354.61	7066.17 ± 2133.39	6865.11 ± 1772.66	6974.55 ± 1510.12
5912.27 ± 1008.52	5708.60 ± 920.60	5564.40 ± 810.65	5437.19 ± 636.96
18.20	23.78	23.38	28.27
0.1419	0.0701	0.0522	0.0193
6370.58 ± 1532.72	6073.26 ± 1453.92	5721.15 ± 1025.14	5770.94 ± 1075.21
5483.20 ± 856.20	5266.18 ± 767.22	5339.83 ± 767.80	5617.63 ± 587.74
16.18	15.33	7.14	2.73
0.1159	0.1279	0.2756	0.3895
7007.58 ± 1935.75	6858.99 ± 1737.45	7008.93 ± 1544.77	7055.81 ± 1337.85
6088.74 ± 987.48	5742.95 ± 837.65	5684.31 ± 775.98	5562.22 ± 664.30
15.09	19.43	23.30	26.85
0.1418	0.0736	0.0333	0.0123

whereas the group with an 8 h $PM_{10} > 110$ μg m^{-3} showed the opposite pattern. To put it differently, when the 8 h mean PM_{10} concentration was low, there was a short-term lag effect up to 3 day lag, whereas when the 8 h mean PM_{10} concentration was high, there was a relatively longer lag effect with a delay of 4 or more days.

The *p*-values from Tables 4 and 6 are represented in the form of a graph for each case of the PM_{10} concentrations and day lags in Figure 3. In general, a *p*-value represents the extent to which the data disagree with the alternative hypothesis (H_1), which is that the number of medical services provided for asthma on the index days is higher than that of the comparison days (Groebner *et al*., 2008). Thus, a small *p*-value indicates that there is actually an increase in the onset of asthma patients after ADS. A comparison of Figure 3(a) and (b) shows that two groups, of which 24 h and 8 h mean PM_{10} concentrations are under 110 μg m^{-3}, have different patterns of lag effects.

4. Concluding remarks

This paper analysed the effect of Asian dust storm (ADS) events on asthma attacks by employing the concepts of lag effects and severity of the ADS (i.e., the degree of PM_{10} concentration level). Results showed that there is a strong association between ADS events and asthma patients for 4–6 days lag. Severe ADS events with mean $PM_{10} > 110$ μg m^{-3} have a more adverse effect on asthma attacks. However, in cases of low PM_{10} levels the percentage increase patterns in asthma treatment counts were completely different depending on the period that the mean PM_{10} concentration measurement was based on (i.e., 24 h or 8 h). In order to investigate the exact cause, behavioural studies on the psychology and life cycles of the general population must be conducted along with pathological analysis. Also, the results suggest that it is important to collect the data on the environmental variables after careful designation

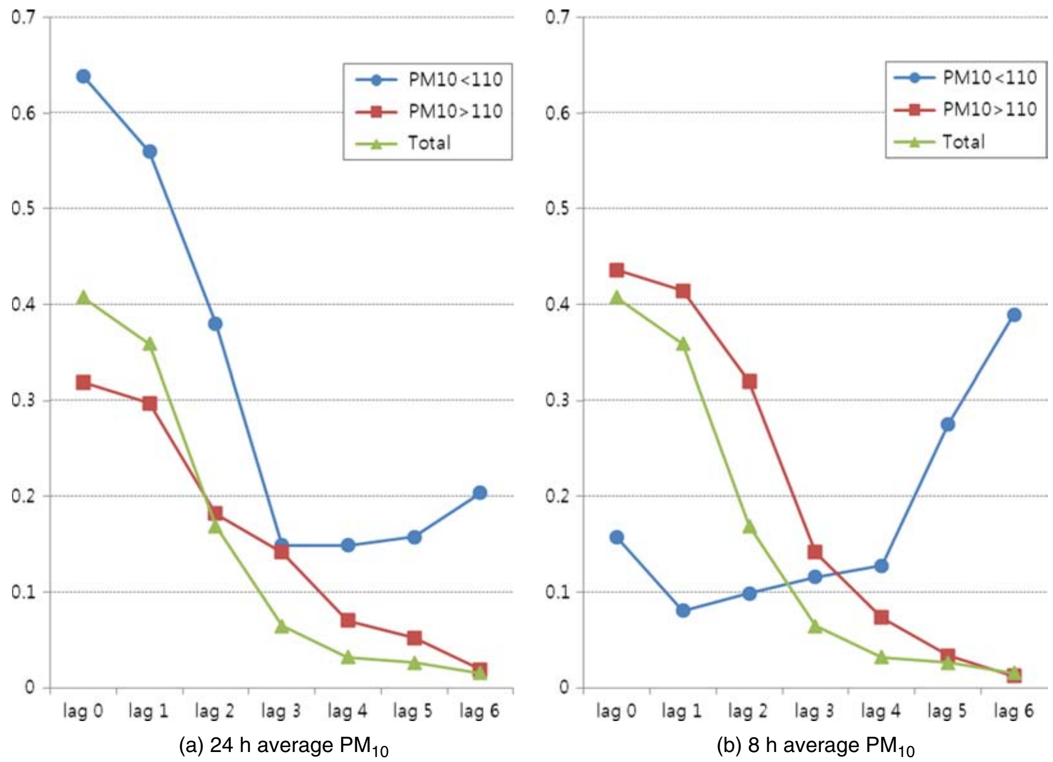

Figure 3. The p-values of paired t-test for groups with PM_{10} < 110 and with PM_{10} > 110 by various lags. This figure is available in colour online at wileyonlinelibrary.com/journal/met

of the appropriate measurement period that meets the purpose of the analysis. In conclusion, this study can be extended to forecast asthma attacks, of which results can be used to organize medical resources and prevent the prevalence of asthma for medical service providers and the public.

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