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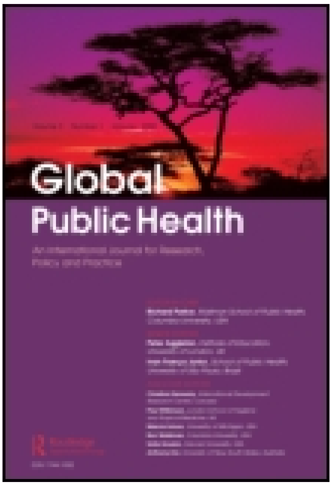

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The threat of Asian dust storms on asthma patients: A population-based study in Taiwan

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This study explores the relationship between Asian dust storms (ADSs), asthma hospital admissions and average medical cost discharge. We adopt the hospitalisation data from the Taiwan National Health Insurance research database covering the period from 2000 to 2009. The autoregressive integrated moving average with exogenous variables (ARIMAX) analyses were performed to explore the relationship between ADS and asthma hospital admissions, adjusting for temperature, air pollutants and season dummy. The results show that ADS events do generate a critical influence upon the occurrences of asthma on post-ADS events from days 1 through 3, with an average of 17–20 more hospitalised admissions, and have stronger effects on preschool children, middle-aged people and the elderly. From the perspective of medical expenses, the cost of hospitalised admissions for asthma substantially rises daily, on average, by NT$634,698 to NT$787,407 during ADS event days. This study suggests that government should establish a forecast and alert system and release warnings about dust storms, so that the individuals predisposed to asthma can take precautionary measures to reduce their outdoor exposure. Consequently, personal risk and medical expenditure could be reduced significantly, especially for preschool children, middle-aged people and the elderly with asthma.

Keywords: Asian dust storm; asthma; hospitalisation; ARIMAX; Taiwan

Introduction

Wind-blown mineral and soil particles in arid and semi-arid areas such as the Taklamakan Desert, Gobi Desert and Loess Plateau in inland China and Mongolia are often carried by westerly winds to Northeast Asia, including Taiwan, where dust storms are frequently observed in spring. Such wind-blown dust is known as an Asian dust storm (ADS). The frequency of ADS events in Taiwan has increased from the 1990s to the 2000s (Chan, 2002). The major cause of these ADS events are due to stronger winds in the deserts along with the desertification of land surface conditions in China and Mongolia (Kurosaki, Shinoda, & Mikami, 2011). One possible factor for the desertification of grasslands and cultivated lands is from climate change and human activities such as over-cultivation and overgrazing. The occurrence of these ADS events has led to the higher levels of particulate matter (PM) over that contributed by the usual local sources and is associated with deleterious health effects.

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Some studies have demonstrated a relation between increased levels of ambient PM and greater morbidity and mortality of cardiopulmonary diseases (Pope et al., 2002; Samet, Dominici, Curriero, Coursac, & Zeger, 2000). Other studies have found significant association between PM and stroke admissions (Pönkä & Virtanen, 1996; Wordley, Walters, & Ayres, 1997). Furthermore, research findings have shown significant increases in PM with aerodynamic diameters of <10 μm in urban areas during ADS events (Var, Narita, & Tanaka, 2000), demonstrating adverse health effects associated with such increases in particulate pollution in South Korea and Taipei (Chen et al., 2004; Kwon, Cho, Chun, Lagarde, & Pershagen, 2002). Recent epidemiologic studies indicated that ADS particles may cause pulmonary inflammation (Lei, Chan, Wang, Lee, & Cheng, 2004), allergic rhinitis (Chang, Lee, Tsai, & Yang, 2006), conjunctivitis (Yang, 2006) and contact dermatitis (Choi et al., 2011; Otani, Onishi, Mu, & Kurozawa, 2011).

The literature has enlarged its discussion of the health impact from ADS events by comparing the use of hospitalised admissions between ADS and non-ADS events, yet the results of the influence of ADS events on admissions are still diverse. Yang, Chen, Chiu, and Goggins (2005) demonstrated a statistically significant association between ADS events and primary intra-cerebral haemorrhagic stroke admissions within 3 days after a dust event, but an insignificant association between ADS events and ischemic stroke admissions, while Kang, Liu, Keller, and Lin (2013) found post-ADS days 1 and 2 have significantly higher numbers of ischemic, but not haemorrhage, stroke admissions. Statistically significant associations have also been presented between ADS events and hospital admissions for children's respiratory diseases, cardiopulmonary diseases and pneumonia (Chan et al., 2008; Kang, Keller, Chen, & Lin, 2012; Yu, Chien, & Yang, 2012). Nevertheless, several studies have found that ADS events may be insignificantly associated with the risk of hospital admissions for cardiovascular disease, chronic obstructive pulmonary disease and congestive heart failure (Chen & Yang, 2005; Chiu et al., 2008; Yang, Cheng, & Chen, 2009).

Even though an increasing number of studies have estimated the harmful effects of ADS events on hospitalised admissions, only a finite number of them particularly focused on the impact of ADS events on asthma hospitalised admissions. Moreover, the existing literature presents limited and contradictory results. For example, Thalib and Al-Taiar (2012) found that dust storms in Kuwait have a significant impact on respiratory and asthma admissions by using data on emergency hospital admissions. For Seoul, South Korea, Yoo, Choung, Yu, Kim, and Koh (2008) indicated that ADS events increase the risk of acute respiratory symptoms and pulmonary function deterioration in children with mild asthma. Kanatani et al. (2010) suggested that heavy ADS events in Japan are significantly associated with an increased risk of asthma admissions for children with asthma, while Watanabe et al. (2011) designed a telephone survey and found that ADS events aggravate lower respiratory symptoms in adult patients with asthma, but this impact is mild. Therefore, the results of the impact of ADS exposure on hospital admissions for asthma are still unclear and limited.

During 2000–2009, Taiwan experienced 46 storm events categorised as ADS. These ADS events make up a total period of 135 dust storm days, but few have investigated the association between ADS events and asthma admissions in Taiwan. Only Yang, Tsai, Chang, and Ho (2005) found that ADS events could increase the risk of daily asthma admissions in Taipei, although the association is not statistically significant. To fill this gap in the literature, using 10-year population-based data, this study examines the association of ADS events with the daily number of asthma admissions in Taiwan. To the best of our knowledge, this is the largest and most complete population-based study to investigate the impact of ADS events on asthma hospital admissions using adequate time series analysis.

Methods

Data

The data in this study include asthma admission data, dust storm data, meteorological data and air pollution data. We obtain the data on asthma hospitalisation admissions from the National Health Insurance (NHI) research database. More than 99% of the population is enrolled in the NHI programme in Taiwan, and since all hospitalisation records have to be filed with the Bureau of NHI for medical benefit claims, we are able to retrieve those patients with asthma hospitalisation from the database. From the NHI research database, we extracted inpatient claims data for all patients in Taiwan admitted during January 2000 to December 2009 with a principle diagnosis of asthma or asthmatic bronchitis (ICD-9-CM code 493). All the admissions were regarded as discrete episodes, even if a patient had multiple admissions during the sample period.

We retrieve data of dust storm events and the daily average concentration of air pollutants from the air quality monitoring data banks of Taiwan Environmental Protection Agency (TEPA), which monitors the daily air quality at 55 stations across the country. TEPA declares that an ADS event has begun to influence Taiwan if the concentration of the total atmospheric PM at the stations increases to 100 $\mu g\ m^{-3}$ or above from the long-term average concentration of 50 $\mu g\ m^{-3}$. The priority air pollutants measured by the TEPA include PM_{10}, SO_2, CO, O_3 and NO_2. This study uses the daily mean data from these 55 observatories to calculate the daily mean levels of the air pollutants. We obtain the daily mean ambient temperature data from the Taiwan Central Weather Bureau, Ministry of Transportation and Communication. For calculating the daily ambient temperatures, this paper averages the ambient temperature data by day. We calculate the mean meteorological data on ambient temperatures from the daily data provided by the 23 weather observatories in Taiwan.

Modelling asthma admissions

In order to examine the ADS effects on asthma admissions amongst the different gender and age groups, we divide the observations into appropriate groups. The main explanatory variable used in this paper is ADS. Because an ADS has prolonged effects on asthma admissions, the traditional ordinary least squares (OLS) model does not capture the lag effects between asthma admissions and the effects of post-ADS events. For modelling the dynamic effects between asthma admissions and the effects of post-ADS events, this study uses dummy variables to control the post-ADS period. We set up seven different dummy variables to control the post-ADS effect from day 1 to day 6. We implement the time series model to investigate the dynamic relationships among asthma admissions and ADS events.

According to Chen, Xirasagar, and Lin (2006) and Xirasagar, Lin, and Liu (2006), the important factors that impact asthma admissions are temperature, season and air pollutants. In addition to the ADS variable, this study adds ambient temperatures, SO_2, CO, O_3 and season dummy variables to control other factors that may influence asthma admissions.

The autoregressive integrated moving average with exogenous variables (ARIMAX) model considered in this study is as follows:

$$\mathrm{Asthma_t} = \beta_0 + \beta_1 \mathrm{Trend} + \sum_{j=1}^{6} G_j + X_t\delta + \varepsilon_t \tag{1}$$

where $\mathrm{Asthma_t}$ is the number of asthma hospital admissions in Taiwan, Trend is the deterministic time trend, G_j is a dummy variable for the jth day after ADS, X_t are other controlled exogenous variables including temperature, SO_2, CO, O_3 and a season dummy for spring, autumn and winter and ε_t is the error item.

The main benefit from the ARIMAX regression model is that the ARIMAX model like Equation (1) can analyse post-ADS event effects on asthma hospital admissions. Some asthma patients might not have serious symptoms until 2–4 days after an ADS event. If we only use OLS models, then the delayed effects on asthma hospital admissions cannot be found. This study uses the time series ARIMAX regression to explore the dynamic effects between asthma hospital admissions and ADS and post-ADS events. Because the error sequence generally has serial correlations, we choose MA(1) based on Akaike Information Criterion (AIC) to control the possible serial correlations in residuals.

Asthma is a costly disease to treat. For estimating approximate cost of the extra medication in the periods of ADSs, we roughly calculate the average medical expenditure of per asthma admission from NHI database, which is equal to the summation of each asthma hospitalisation expenditure from 2000 to 2009 divided by the total amount of hospitalised admissions due to asthma. The extra daily total medical cost due to ADS can be simply calculated by the following equation:

$$\text{Extra daily cost} = \text{average medical expenditure} \times N,$$

where N is the extra amount of asthma admissions due to ADS. From the estimation results, we may infer the extra medical cost on NHI during the ADS periods.

Results

Table 1 presents the demographics of asthma hospitalisation. Of the number of 614,742 asthma hospitalisations, 53.3% were male. Their age distribution is as follows: <6 years = 22%; 7–17 years = 5%; 18–44 years = 10.1%; 45–74 years = 36.2%; and >74 years = 26.7%. The mean costs of hospitalisation are NT$38,681 (US$1 = NT$33.5 in 2005). The highest hospitalisation cost of NT$62,644 is for people older than 74 years old, while the lowest cost of NT$13,035 is for those between 7 and 17 years old.

Figure 1 depicts the trend in hospitalised admissions of asthma during ADS events for the total group and sex group. The total group shows a distinct daily pattern with the highest mean number of 216.6 admissions for post-ADS day 2. The male and female groups have a similar trend, rising from the ADS day (109.3 and 92.9 admissions for them, respectively) to peak admissions of 117.7 for men on post-ADS day 2 and peak admissions of 100.1 for women on post-ADS day 3, followed by a decline.

Among different age groups, Figure 2 illustrates that juveniles and prime adults (7- to 17-year-olds and 18- to 44-year-olds, respectively) have the lowest hospitalised admissions and no significant variation of admissions during ADS event days, while middle-aged people (45- to 74-year-olds) have the most admissions and a peak number of 82.9 admissions on post-ADS day 2. Preschool children and the elderly (0- to 6-year-olds

Table 1. Average daily asthma hospitalisation and average medical expenditure according to gender and age group.

	Average daily asthma inpatient									
	No D	Dust-S	PD day 1	PD day 2	PD day 3	PD day 4	PD day 5	PD day 6	Average medical expenditure	Observations
Total	164.3	202.2	208.3	216.6	214.1	198.8	197.1	195.3	38,681.1	614,742 (100%)
Gender										
Male	87.5	109.2	109.3	117.7	113.9	106.7	104.6	104.1	36,616.6	327,678 (53.3%)
Female	76.8	92.9	98.9	98.7	100.1	92.0	92.2	91.1	41,037.8	287,064 (46.7%)
Age										
0–6	35.9	46.7	47.3	48.1	49.1	46.7	43.5	43.2	13,122.6	134,976 (22%)
7–17	8.2	8.5	9.9	9.3	10.4	10.2	9.2	9.3	13,035.0	30,471 (5%)
18–44	16.8	19.5	20.2	21.4	20.6	17.2	19.6	18.0	26,494.1	62,233 (10.1%)
45–74	59.4	73.0	75.7	82.9	78.6	70.6	71.5	74.3	43,417.9	222,893 (36.2%)
>74	43.9	54.3	55.2	54.7	55.4	54.0	53.0	50.3	62,643.6	164,169 (26.7%)

No D, no dust storm; Dust-S, day of dust storm; PD day 1, post-dust day 1.

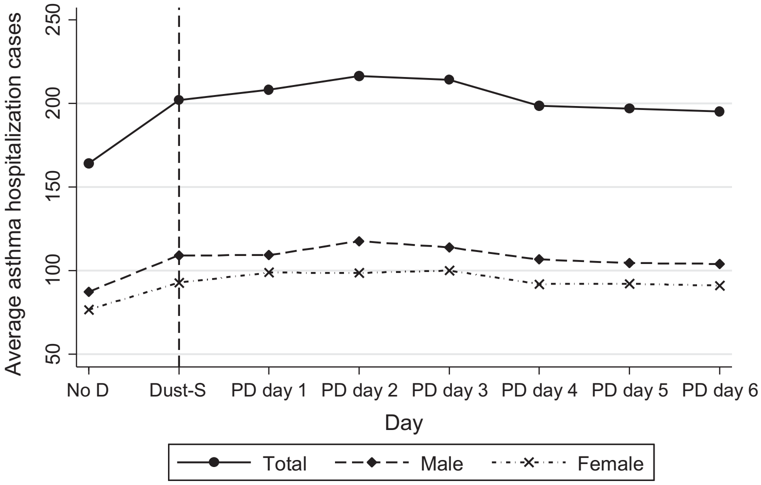

Figure 1. Average daily asthma hospital admissions by days after dust storm and gender, Taiwan, 2000–2009.
Note: No D: No dust-storm; Dust-S: Day of dust-storm; PD day 1: Post-dust day 1

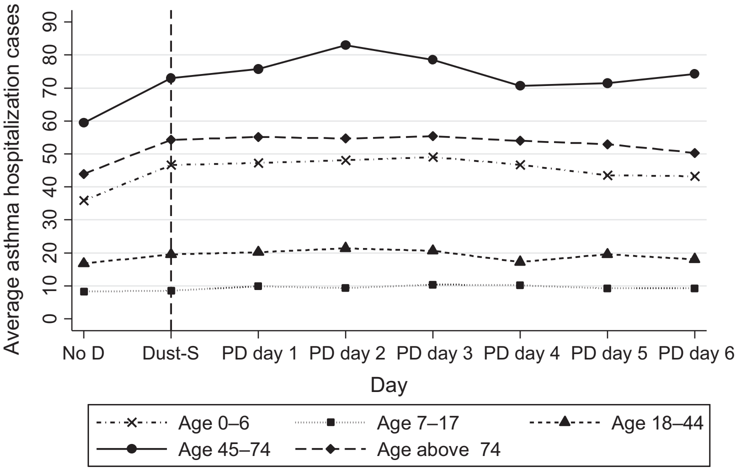

Figure 2. Average daily asthma hospital admissions by days after dust storm and age, Taiwan, 2000–2009.
Note: No D: No dust-storm; Dust-S: Day of dust-storm; PD day 1: Post-dust day 1

and above 74 years old, respectively) have high asthma admissions on the ADS day, which then remain stable from post-ADS days 1 through 3.

Table 2 shows the ARIMAX result for the relationship between ADS events and the mean number of daily asthma hospital admissions. After controlling for the time trend effect, ambient temperature, air pollutants (SO_2, CO and O_3) and seasonal factors, the results in the first column exhibit significant variations of occurrences for asthma in the ADS event days. Using non-ADS event days as the reference days, we find that the impact from the day of ADS invasion has an insignificant effect on hospitalised admissions for asthma. However, we note there is a significant peak number of hospitalisations for asthma on post-ADS event day 2, with approximately 20.35 more admissions, and then the next significant number of asthma admissions is 19.98 more on post-ADS event day 3, and

Table 2. ARIMAX regression analysis for the relationship between dust storm and number of daily asthma admissions according to gender.

	Number of daily asthma admissions								
	Total			Male			Female		
Independent variable	*B*	SE	*p* value	*B*	SE	*p* value	*B*	SE	*p* value
Intercept	226.6189	16.833	0.000***	124.3898	9.4932	0.000***	102.4726	8.250	0.000***
Trend	−0.0199	0.001	0.000***	−0.0150	0.0008	0.000***	−0.0047	0.000	0.000***
Temperature	−1.5718	0.360	0.000***	−0.6575	0.2034	0.001**	−0.9271	0.177	0.000***
SO_2	−1.7166	1.635	0.293	−0.7550	0.9216	0.412	−0.9899	0.800	0.216
CO	23.0922	15.178	0.128	14.0579	8.5538	0.100	9.1912	7.424	0.215
O_3	−0.2876	0.372	0.439	−0.2413	0.2096	0.249	−0.0509	0.182	0.779
Time since dust storm									
Day of dust storm	2.0696	5.131	0.686	1.7412	2.8999	0.548	0.5026	2.530	0.842
Post-dust day 1	16.4085	7.234	0.023*	6.7976	4.1107	0.098	9.4709	3.618	0.008**
Post-dust day 2	20.3564	7.965	0.010*	12.0371	4.5218	0.007**	8.3972	3.975	0.034*
Post-dust day 3	19.9853	8.088	0.013*	9.3915	4.5906	0.040*	10.7000	4.034	0.008**
Post-dust day 4	5.04035	8.424	0.549	2.5200	4.7812	0.598	2.5663	4.202	0.541
Post-dust day 5	2.2201	8.417	0.792	0.6601	4.7855	0.890	1.7113	4.216	0.684
Post-dust day 6	0.1909	6.788	0.977	0.0165	3.8415	0.996	0.4277	3.358	0.898
Spring	32.9643	4.951	0.000***	17.0102	2.7905	0.000***	15.8599	2.422	0.000***
Autumn	10.2544	4.084	0.012*	8.4759	2.3021	0.000***	1.7840	1.998	0.372
Winter	19.6813	5.113	0.000***	10.7667	2.8837	0.000***	8.7524	2.506	0.000***
MA1	0.2367	0.017	0.000***	0.2240	0.0170	0.000***	0.2026	0.017	0.000***
AIC		10.5616			9.4344			9.1851	
SC		10.5932			9.4660			9.2167	
R^2		0.30416			0.3439			0.2196	

Note: Selection of the final parameters was based upon the lowest AIC and SC.
MA1, moving average, lag 1; reference group: No dust storm.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 3. ARIMAX regression analysis for the relationship between dust storm and number of daily asthma admissions according to age group.

	Number of daily asthma admissions								
	0–6			7–17			18–44		
Independent variable	*B*	SE	*p* value	*B*	SE	*p* value	*B*	SE	*p* value
Intercept	52.4865	4.355	0.000***	13.7684	1.426	0.000***	25.3752	2.417	0.000***
Trend	−0.0030	0.000	0.000***	0.0005	0.000	0.000***	−0.0018	0.000	0.000***
Temperature	−0.3480	0.093	0.000***	−0.2167	0.030	0.000***	−0.2408	0.052	0.000***
SO_2	−0.2109	0.421	0.617	1.1268	0.138	0.000***	0.2205	0.233	0.345
CO	−0.2978	3.914	0.939	−2.5561	1.285	0.046*	0.7026	2.169	0.746
O_3	−0.3742	0.095	0.000***	−0.2611	0.031	0.000***	−0.0845	0.053	0.111
Time since dust storm									
Day of dust storm	2.4379	1.339	0.068	−1.1007	0.435	0.011*	−0.4968	0.746	0.505
Post-dust day 1	5.6562	1.932	0.003**	−0.0592	0.617	0.923	0.8619	1.087	0.428
Post-dust day 2	5.1899	2.120	0.014	−0.0518	0.678	0.939	2.1878	1.192	0.066
Post-dust day 3	6.3651	2.151	0.003**	1.2015	0.689	0.081	1.3200	1.209	0.275
Post-dust day 4	3.5889	2.241	0.109	0.7929	0.717	0.269	−1.9312	1.260	0.125
Post-dust day 5	0.4408	2.253	0.844	−0.2282	0.718	0.750	0.4808	1.269	0.704
Post-dust day 6	−0.1766	1.782	0.921	−0.1254	0.576	0.827	−1.1512	0.995	0.247
Spring	16.8480	1.277	0.000***	3.5843	0.419	0.000***	2.2390	0.708	0.001**
Autumn	11.0644	1.053	0.000***	2.3240	0.345	0.000***	0.6842	0.584	0.241
Winter	6.0814	1.323	0.000***	1.9837	0.433	0.000***	2.2402	0.734	0.002**
MA1	0.1840	0.017	0.000***	0.2261	0.017	0.000***	0.1616	0.017	0.000***
AIC		7.9351			5.6408			6.7917	
SC		7.9667			5.6724			6.8233	
R^2		0.2735			0.2479			0.1568	

Table 3 (*Continued*)

	Number of daily asthma admissions					
	45–74			>74		
Independent variable	*B*	SE	*p* value	*B*	SE	*p* value
Intercept	79.8359	6.875	0.000***	55.5317	5.471	0.000***
Trend	−0.0107	0.000	0.000***	−0.0048	0.000	0.000***
Temperature	−0.5717	0.147	0.000***	−0.2165	0.117	0.065
SO_2	−2.2170	0.667	0.000***	−0.6619	0.529	0.211
CO	18.3324	6.198	0.003**	7.2925	4.914	0.137
O_3	0.4207	0.151	0.005**	0.0059	0.120	0.960
Time since dust storm						
Day of dust storm	−1.2995	2.096	0.535	2.7781	1.686	0.099
Post-dust day 1	4.4911	2.959	0.129	5.1986	2.446	0.033*
Post-dust day 2	9.7078	3.257	0.002**	3.4316	2.683	0.201
Post-dust day 3	6.1833	3.307	0.061	5.0625	2.721	0.063
Post-dust day 4	−1.1565	3.445	0.737	3.8013	2.835	0.180
Post-dust day 5	−0.1971	3.443	0.954	2.0538	2.853	0.471
Post-dust day 6	1.9470	2.774	0.482	0.0626	2.247	0.977
Spring	5.4735	2.022	0.006**	4.6445	1.604	0.003**
Autumn	−3.2859	1.668	0.049*	−0.5558	1.322	0.674
Winter	5.5388	2.088	0.008**	3.5297	1.662	0.033*
MA1	0.2342	0.017	0.000***	0.1719	0.017	0.000***
AIC		8.7745			8.4097	
SC		8.8061			8.4412	
R^2		0.3367			0.1654	

Note: Selection of the final parameters was based upon the lowest AIC and SC.
MA1, moving average, lag 1; reference group: No dust storm.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

16.41 more on post-ADS event day 1. In other words, compared with non-ADS and ADS event days, post-ADS events from days 1 through 3 have a significantly greater mean number of asthma hospital admissions for the total group.

For climatic factors, the admissions of asthma hospitalisation steadily increase as the ambient temperature drops. The levels of air pollutant evidently have no influence on the number of hospitalisations due to asthma. Moreover, a seasonal effect on the occurrences of asthma is discernible, with the number of hospitalisations for asthma increasing significantly during spring and winter. The seasonal effect is most pronounced in spring, with 33 more daily hospitalisations for asthma than in summer. Finally, there is a clear and significant downward time trend, suggesting a general decrease in the number of occurrences of asthma between 2001 and 2009.

We next analyse the relationship between ADS and the number of daily asthma admissions stratified by gender. The results show that the day of the ADS event does not significantly affect asthma hospitalisation for both males and females, but that post-ADS days 2 and 3 do have a significantly higher number of asthma admissions than non-ADS days for males, with an increase of 12 and 9 hospitalisations for asthma, respectively. Nevertheless, for females the impact of post-ADS days from 1 through 3 has a statistically significant effect on asthma admissions and, compared with non-ADS event days, is associated with an increase of 9.47, 8.4 and 10.7 more asthma hospitalisations, respectively. The patterns of climatic factors and the seasonal effect are similar to those found in the estimation for the full population sample.

Table 3 presents the results based upon the separation of the data by age. More prominently, we demonstrate that ADS events have a specific impact on preschool children, middle-aged people and the elderly. Compared with non-ADS event days, post-day 1 and post-day 3 for the ADS event present 5.66 and 6.37 more hospitalisations for asthma, respectively, among the 0–6 age group, while the impact from the day of the ADS event has an insignificant effect on asthma admissions for the same group. Moreover, we find that ADS events result in significantly higher numbers of hospitalised admissions for asthma by 9.71 in post-day 2 for the 45–74 age group and by 5.2 in post-day 1 for the above 74 age group.

Neither ADS event days nor post-ADS event days are found to have significant impacts on the occurrences of asthma for the 7–17 age and the 18–44 age groups, except for a weak significance with ADS event days for the 7–17 age group. For climatic factors, we see that ambient temperature and the seasonal effects exist in each of the five age groups, with temperature insignificant for the elderly group. A point worth noting, however, is that the seasonal effect is stronger for the preschool children group. Finally, the time trend is positively significant for the 7–17 age group but negatively significant for the other age groups.

Our results suggest that ADS events do generate a critical influence upon the occurrences of asthma hospitalisation on post-ADS event days from 1 to 3, with an average of 17–20 more hospitalised admissions, and have stronger effects on preschool children, middle-aged people and the elderly. From the perspective of medical expenses, the cost of hospitalised admissions for asthma substantially rise daily, on average, by NT$634,698 (= 16.4085 × NT$38,681.1) to NT$787,407 (= 20.3564 × NT$38,681.1) during ADS event days, specifically NT$83,526 (= 6.3651 × NT$13,122.6) for preschool children, NT$421,192 (= 9.7078 × NT$43,417.9) for middle-aged people and NT$325,695 (= 5.1986 × NT$62,643.6) for the elderly.

Discussion

The purpose of this study is to investigate the relationships between ADS and asthma hospital admissions. Some studies have explored the elements that cause hospital admissions for asthma before, but the short-term impact on asthma admissions from an ADS is not well documented to date. To fill this possible gap, this paper examines population-based data obtained from the NHI research database and constructs ARIMAX models to analyse the causality between asthma hospital admissions and ADS effects.

After adjusting for time trend, temperature, season, SO_2, CO and O_3, our results show that, compared to non-ADS events, post-ADS event days 1–3 have distinct high mean numbers of asthma admissions (16.41, 20.35 and 19.98 more, respectively) for the total group. In addition, there is an average daily increase for medical expenses of NT$634,698 to NT$787,407 due to asthma hospitalisation during post-ADS event days. When we repeat the ARIMAX regression analyses after stratification by gender, the asthma admissions for post-ADS event days 2–3 have a significantly higher mean number than non-ADS days for all gender groups.

Another noteworthy finding is that an ADS event has significant impacts on asthma admissions for the groups of preschool children and over 45 year olds. From the ARIMAX regression outcome stratified by age, this paper finds that ADS event days present delayed effects on asthma admissions. The asthma admissions for age 0–6 in post-ADS event day 1 and day 3, for age 45–74 in post-ADS event day 2, and for age over 74 in post-ADS event day 1 are all significantly higher than those in non-ADS days. The number of asthma admissions for ages 0–6, 45–74 and over 74 for post-ADS event days 1 to 3 are clearly 5–10 more than for non-ADS event days. In order to reduce the medical cost of asthma hospitalisation, policy-makers in Taiwan should warn the elderly, preschool children and people who have respiratory diseases to avoid outdoor activities on the first 3 or 4 days of an ADS event.

Our results are consistent with previous studies done by Thalib and Al-Taiar (2012), Kanatani et al. (2010) and Yoo et al. (2008), who found a significant relationship between ADS events and asthma hospital admissions. However, Yang, Tsai, Chang, and Ho (2005) noted that the effect of ADS on asthma admissions is not statistically significant. The discrepancy might come from the study sampling and statistical modelling. Yang, Tsai, Chang, and Ho (2005) used asthma admissions in Taipei City during 1996–2001. In our study, we take population-based asthma admissions data in Taiwan between 2000 and 2009. The results from a sufficient sample size are more reliable. Moreover, the time series ARIMAX model examines the dynamic effects between ADS events and the daily numbers of asthma hospital admissions. One can use an adequate time series model to avoid any variation caused by different time trends (Kang et al., 2012). The adoption of the ARIMAX model also differentiates our study from previous studies.

Our findings on the relationships between post-ADS event days and asthma hospital admissions have implications for policy-makers and health providers in countries suffering from dust storms all around the world. Dust storms are not limited to Asia but also occur in North America, South America, Europe, Africa and Australia. Governments should establish a forecast and alert system and release warnings about dust storms, so that individuals predisposed to asthma can take precautionary measures to reduce their outdoor exposure. Consequently, personal risk and medical expenditure could be reduced significantly especially for preschool children, middle-aged people and the elderly with asthma.

Three limitations in this study need to be pointed out. First, we are unable to know personal exposure levels during ADS events. The NHI inpatient data only provide records for patients with asthma without indicating what caused the hospitalisation. Second, we do not take into account the degree of severity of each ADS event. Air quality and toxic level may vary in different ADS events, which might affect the risk of asthma hospitalisation. Third, it is noteworthy that the extra cost between post-ADS day and other days is a crude estimate. Differences in hospital types will result in different per-admission cost, which is relevant to the cost analysis of the increase in admissions during post-ADS day. Future studies are needed to clarify these issues.

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