Science of the Total Environment 433 (2012) 347–351

Contents lists available at SciVerse ScienceDirect

Science of the Total Environment

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

Dust storms and the risk of asthma admissions to hospitals in Kuwait

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ARTICLE INFO

Article history:
Received 28 December 2011
Received in revised form 9 June 2012
Accepted 25 June 2012
Available online 20 July 2012

Keywords:
Dust storm
Sandstorm
Respiratory
Asthma
Middle East
Kuwait

ABSTRACT

Objective: Arid areas in the Arabian Peninsula are one of the largest sources of global dust, yet there is no data on the impact of this on human health. This study aimed to investigate the impact of dust storms on hospital admissions due to asthma and all respiratory diseases over a period of 5 years in Kuwait.
Methods: A population-based retrospective time series study of daily emergency asthma admissions and admissions due to respiratory causes in public hospitals in Kuwait was analyzed in relation to dust storm events. Dust storm days were defined as the mean daily $PM_{10}>200$ μg/m^3 based on measurements obtained from all six monitoring sites in the country.
Findings: During the five-year study period, 569 (33.6%) days had dust storm events and they were significantly associated with an increased risk of same-day asthma and respiratory admission, adjusted relative risk of 1.07 (95% CI: 1.02–1.12) and 1.06 (95% CI: 1.04–1.08), respectively. This was particularly evident among children.
Conclusion: Dust storms have a significant impact on respiratory and asthma admissions. Evidence is more convincing and robust compared to that from other geographical settings which highlights the importance of public health measures to protect people's health during dust storms and reduce the burden on health services due to dust events.

1. Introduction

Evidence that links ambient air pollutants and adverse health effects has been accumulating over the last couple of decades (Middleton et al., 2008; Wilson et al., 2004). The strongest and most convincing evidence came from meta-analyses of both single-city (Bell et al., 2005b; Levy et al., 2000) and multi-city studies (Ballester et al., 2002; Le Tertre et al., 2002) as well as multi-center European studies with common protocol in 15–29 European cities conducted by the APHEA project (Aga et al., 2003; Analitis et al., 2006; Samoli et al., 2006) and the National Morbidity, Mortality and Air Pollution Study (NMMAPS) of the US cities (Dominici et al., 2005, 2006). However, focus of these studies has been on the assessment of the health effects of pollutants such as ozone, SO_2, CO and particulate matter.

Little information is available on the assessment of health effects in relation to dust storms and none from the Middle Eastern region despite the frequent dust storms that the region experiences. Moreover, previous reports from other parts of the world on the health effects of major dust events have been conflicting. Studies linking dust storm events to short-term mortality have reported either significant association (Ostro et al., 1999; Perez et al., 2008), no association (Schwartz et al., 1999) or an association that is not statistically significant (Chen et al., 2004; Kwon et al., 2002). Several studies from various geographical settings have looked into the short-term health effects of dust storms in terms of hospital admissions and reported a significant association between dust storms and all-cause admissions (Middleton et al., 2008), emergency admissions (Barnett et al., 2012) or admissions due to stroke (Yang et al., 2005a). Studies in Asia (Chen and Yang, 2005; Yang et al., 2009) and Cyprus (Middleton et al., 2008) have reported a statistically non-significant association between hospital admissions due to cardiovascular diseases and dust storm events. Other studies have reported a significant increase in admission due to asthma (Gyan et al., 2005; Kanatani et al., 2010) and pneumonia (Cheng et al., 2008) or an increase in the overall respiratory hospitalization (Tao et al., 2012) during dust storm days while studies in Australia (Barnett et al., 2012) and North America (Bennett et al., 2006) showed no increase in respiratory admissions during dust storm events.

Despite these findings, the impact of dust storms on health has recently attracted attention as some researchers have postulated that dust storm events could potentially transmit bacterial (Leski et al., 2011; Polymenakou et al., 2008) and viral (Chen et al., 2010) infections, which may suggest that the possible impact of dust storms on human health may be beyond that is currently recognized. Moreover, the impact of dust storms are also thought to vary between different geographic regions not only because of varying dust compositions but also due to differences in other factors such as type of housing, time-spent outdoors, access to health care, population characteristics, baseline health status, air pollutant mixture, and the climatic condition (Bell et al., 2005a). As such the health impact of dust storms may not be uniform across the

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doi:10.1016/j.scitotenv.2012.06.082

globe and further evaluation from different geographic regions should improve our understanding significantly.

Countries in the Arabian Peninsula, in particular, experience windblown dust storms several times each year and are one of the principal sources of global dust (Washington et al., 2003) and the researchers have predicted that dust storm events over Kuwait, for instance, occur at least 18% of the year (Draxler et al., 2001). Yet, there is no published data, to our knowledge, on the health impact of dust storm from the Arabian Peninsula or from the broader Middle East, despite the episodes of regular windblown dust storms in a frequency and an intensity that are not experienced by the European or US cities. Moreover, epidemiological data showed that areas impacted by desert dust storms such as communities in the Middle East seem to have higher prevalence of asthma (Abal et al., 2010; Al-Dawood, 2000) compared to European countries, particularly in the pediatric population. Nonetheless, there is little scientific work that could link the dust events to short-term health in this region, mainly due to the difficulties in measuring the daily dust levels as well as complex statistical modeling that needs to account for serial correlations, weather variables and long-term trends that confound the association. In this context, we collected daily level data on age-specific hospital admissions in all public hospitals in Kuwait as well as daily data on dust particles and weather variables for a five-year period. Our focus was on asthma admissions as well as on all respiratory admissions as we hypothesized that major dust storm events could trigger more asthma and respiratory admissions (Abal et al., 2010; Al-Dawood, 2000; Al Frayh et al., 2001).

2. Material and methods

Kuwait is an oil-rich country in the Arabian Peninsula, between latitudes 28.30 and 30.06 North, and longitudes 46.30 and 49.00 East. It has an arid climate with hot long dry summer and cool mild winter. Sandstorms and dust storms occur throughout the year, especially in the period from March to August. Dust storms in the area have been described previously (Draxler et al., 2001; Kutiel and Furman, 2003; Pease et al., 1998; Washington et al., 2003) and it is estimated that they occur at least on 18% of the days in Kuwait and on average, in Riyadh city in Saudi Arabia, 76 days per year had dust storms during which blowing dust reduced visibility to less than 11 km (Washington et al., 2003). Kuwait's terrain is mostly desert with only 5–6% of the land inhabited and the economy depends on the oil-production and oil refinery. Environmental Public Authority (EPA) in Kuwait, which is a signatory for a number of international air pollution control treaties, regularly collects national data on air pollution including particulate matter. Kuwait has a small population of about 3.6 million that is served by six public hospitals that provide 24-hour emergency care to all residents in Kuwait.

2.1. Data on hospitals' admission

Data on daily emergency hospital admissions for Kuwait occurring between January 1996 and December 2000 were obtained from the Department of Vital Statistics of the Ministry of Health, Kuwait. Only emergency admissions were considered while pre-scheduled admissions, transfer from other hospitals or admissions arranged through a clinic were excluded from the analysis. These admissions are unlikely to be related to dust storms even if they occur on the day on which dust events occur. The diagnostic categories of admission provided were according to the International Classification of Diseases version 10 (ICD-10). Respiratory admissions were identified by the ICD-10 codes J00–J98.9 and asthma subsets were identified by ICD-10 codes J45.0–J45.9. The hospital admission data also included the age and the gender of the admitted patients that were used in age stratified analyses. Three age groups were examined; 0–14 years, 15–64 years, and 65 + years.

2.2. Identification of dust storm days and meteorological data

Air pollution data were obtained from the Environment Public Authority (EPA) of Kuwait. Unprocessed air pollution data that was collected from all six national monitoring sites during the period of January 1996 to December 2000 were made available for this study. The data consists of the daily every 5 min readings of PM_{10} in micrograms per cubic meter (μg/m^3). The daily mean values were calculated from the 5 min readings of all the 6 monitoring sites. The network hourly average value and hence the daily mean, minimum and maximum values were calculated for $PM_{10.}$ When data were missing for a particular monitoring station on a given day, the mean values from the remaining sites were used to compute the average. Data on PM_{10} were either missing or unusable in 135 (7.5%) days.

It has been suggested that PM_{10} levels above 200 μg/m^3 indicate small or medium scale dust events in Iraq, Kuwait and Saudi Arabia (Draxler et al., 2001). Thus days that had PM_{10} levels that exceeded 200 μg/m^3 were considered to be dust storm days. Daily mean PM_{10} were coded into 2 groups: for dust ≤ 200 μg/m^3 and > 200 μg/m^3. Other studies have used PM_{10} lower cut off values such as 150 μg/m^3 (Middleton et al., 2008) or even lower (Bell et al., 2008; Cheng et al., 2008; Yang et al., 2009). We also collected daily data on minimum and maximum temperatures, rainfall and relative humidity (morning and afternoon levels) for the same study period. Network averages and maximum and minimum levels of meteorological variables such as temperature and relative humidity were computed.

2.3. Data analysis

Daily age-stratified respiratory as well as asthma admissions due to old or new cases were evaluated in relation to dust storm days compared to days without dust storms. As the effects of dust storms, if any, might be delayed over a period of several days, we also evaluated the effects on same day and 1, 2, 3 and 5 days after the storm events to study the lag effects. We used a generalized additive model (GAM) with penalized splines to analyze data on hospital admissions in relation to dust storms after adjusting for covariates. As the daily admission counts typically follow a Poisson distribution, the core analysis was a GAM with log link and Poisson error, which accounted for smooth fluctuations in daily admissions. Our statistical models that estimated the relative risk on admission counts in relation to dust storm events adjusted for temperature, relative humidity, weekday/weekend, long-term trend and seasons as adjustment variables using various smoothing parameters. The partial autocorrelation function (PACF) was used to guide the selection of degrees of freedom for the smoothing level. Residuals of the models were also examined to check the validity of the selected models. All analyses were conducted using MGCV package (Wood, 2011) in R, (Version 2.14.2, 2012; The R Foundation for Statistical Computing). Separate analyses were carried out for the daily total respiratory admission counts as well as asthma admission counts. Different models were also built for each of the three age groups that were considered: 0–14 years, 15–64 years, and 65 + years in addition to all age groups. We repeated the analyses for summer and winter seasons separately and the findings are reported in the text.

3. Results

Of 1692 days in the study period, we identified 569 (33.6%) days with dust storm events (PM_{10} > 200 μg/m^3) of which 39 (6.8%) days with very severe dust storms during which the daily mean PM_{10} level was higher than 1000 μg/m^3. The mean temperature during the cool season was 21 °C but ranged from 4 °C to 47 °C. In summer, the mean temperature was 38 °C (range: 19 to 51 °C) and approximately three quarters of all dust storm events occurred in this season (Table 1). A total of 856,107 emergency hospital admissions occurred over the five-year study period in Kuwait. Of these 88,267 (10.3%)

Table 1
Mean daily levels of meteorological variables and dust levels (network average) in Kuwait, Jan 1996–Dec 2000 (n = 1692 days).

	Cool season[a]		Warm season[b]		Whole study period	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
Temperature (°C)	21.1 (6.2)	3.8–46.7	37.5 (3.4)	19.0–51.3	27.9 (9.6)	3.8–51.3
Humidity (%)	57.8 (18.77)	17.3–100	26.0 (11.0)	11.3–98.4	42.67 (44.5)	11.3–100.0
PM_{10} (μg/m3)	137 (166)	0–4999	314 (294)	0–5038	212 (245)	0–5038
	n/N (%)		n/N (%)		n/N (%)	
Dust storm days	143/972(14.7%)		426/720(59.2%)		569/1692(33.6%)	

[a] October to April.
[b] May to September.

were respiratory admissions including 15,256 (1.8%) asthma emergency admissions. The mean daily admissions stratified by age for asthma and respiratory causes are presented in Table 2. The mean daily asthma admissions and the mean daily admissions due to all respiratory causes were almost ten times higher among children under 15 years compared to those aged 65 years or above.

Age-stratified estimates of the relative risk (RR), 95% confidence intervals (95% CI) and the p-values demonstrating the effect of dust storm events on asthma admissions and respiratory admissions are presented in Tables 3 and 4, respectively. We also presented the lag effects on admission following 1, 2, 3 and 5 days after dust storm events. There was a statistically significant increase in the risk of same-day asthma admission in pediatric population during the dust storm days compared to those without dust storms (Table 3). Relative risk estimates showed an increase rate of asthma admission related to dust storm events in the age group 15–64 although this increase was not statistically significant. Likewise, respiratory admissions that included asthma and all other respiratory causes showed similar trends. With the exception of older patients, age ≥ 65 years, the impact of dust storms on respiratory admissions was evident in all other younger patients including children (Table 4). Our findings suggest that dust storm events associate with 4% to 8% increase in all respiratory admissions. The findings remained unchanged when the analysis was stratified by season, although the impact of dust storms on all respiratory admissions was more evident in winter particularly among children.

4. Discussion

The impact of dust storms on human health has been of great interest and was described in Asia, North America and Australia. In the Middle East and Arabian Peninsula, although dust storms are common, there is no data on the impact of dust events on human health. We have, however, demonstrated that dust storm events were associated with asthma and respiratory admissions to hospitals based on national level data collected from Kuwait for a five-year study period. Our findings showed that dust storms are significantly associated with an increased risk of admission to hospitals due to asthma and respiratory diseases after adjusting for potential confounders, particularly in children. This is similar to that reported from Japan (Kanatani et al., 2010), Trinidad (Gyan et al., 2005) and Taiwan (Yang et al., 2005b) where admission due to asthma increased during or immediately after dust storms although in the later study it was not statistically significant.

Despite the findings of a recent study in Australia where an increase in emergency admissions was found but no increase in respiratory admissions was detected during Australian dust storm days (Barnett et al., 2012), the evidence for adverse effect of dust storms on respiratory health is accumulating from different parts of the world. For instance, a Cypriot study that assessed the effect of short-term changes in PM_{10} on

Table 2
Mean daily asthma and all respiratory admissions stratified by age groups, in Kuwait, Jan 1996–Dec 2000.

Age group	Asthma		Respiratory	
	Mean (SD)	Range	Mean (SD)	Range
<15 years	5.0 (3.2)	0–20	31.2 (12.9)	3–77
15–64 years	2.9 (1.9)	0–11	14.3 (5.4)	1–37
≥ 65 years	0.5 (0.7)	0–4	2.9 (1.9)	0–13
All ages	8.4 (4.2)	0–27	48.5 (16.4)	4–99

Table 3
Association between dust storm events and asthma admissions quantified by Generalized Additive Models with Poisson links.

	Lag	RR[a]	95% CI	p-Value
<15 years	0	1.093	1.032–1.155	0.004
	1	1.029	0.967–1.090	0.373
	2	1.022	0.960–1.084	0.485
	3	0.996	0.934–1.058	0.898
	5	0.983	0.921–1.045	0.595
15–64 years	0	1.062	0.984–1.141	0.131
	1	1.044	0.966–1.123	0.277
	2	1.032	0.954–1.110	0.431
	3	1.034	0.956–1.112	0.405
	5	0.934	0.855–1.013	0.090
≥65 years	0	0.925	0.756–1.094	0.366
	1	0.970	0.803–1.137	0.719
	2	0.891	0.722–1.059	0.177
	3	0.901	0.732–1.070	0.228
	5	0.992	0.826–1.159	0.270
All ages	0	1.071	1.024–1.117	0.004
	1	1.030	0.983–1.077	0.224
	2	1.014	0.967–1.061	0.573
	3	1.001	0.954–1.048	0.976
	5	0.966	0.918–1.013	0.148

[a] Relative risk adjusted for season, long term trend and weather variables.

Table 4
Association between dust storm events and respiratory admissions quantified by Generalized Additive Models with Poisson links.

	Lag	RR[a]	95% CI	p-Value
<15 years	0	1.070	1.045–1.094	<0.001
	1	1.032	1.008–1.057	0.012
	2	1.006	0.981–1.030	0.648
	3	1.026	1.002–1.051	0.038
	5	1.008	0.983–1.032	0.544
15–64 years	0	1.036	1.001–1.070	0.045
	1	1.010	0.975–1.044	0.585
	2	1.019	0.984–1.053	0.291
	3	1.049	1.014–1.083	0.007
	5	0.995	0.960–1.029	0.761
≥65 years	0	0.977	0.900–1.054	0.547
	1	1.027	0.950–1.104	0.493
	2	0.974	0.900–1.049	0.493
	3	1.019	0.942–1.096	0.635
	5	0.951	0.875–1.026	0.191
All ages	0	1.056	1.036–1.075	<0.001
	1	1.027	1.008–1.047	0.007
	2	1.009	0.990–1.029	0.362
	3	1.033	1.014–1.053	<0.001
	5	1.001	0.982–1.021	0.916

[a] Relative risk adjusted for season, long term trend and weather variables.

respiratory health noted a significant increase in respiratory admission during the warm season (Middleton et al., 2008). Dust weather in China was shown to be associated with increase in the respiratory hospitalization (Tao et al., 2012) while in Hong Kong dust storms were significantly associated with hospital admission due to chronic obstructive pulmonary diseases (Tam et al., 2012).

The impact of dust storm events on respiratory admissions, particularly asthma admission, in our settings seems to be more obvious with relatively higher relative risk estimates than other settings. This is probably because dust storms in our settings, occur more frequently and last longer than dust storms in other settings despite the higher PM_{10} level we have used to define dust storm events ($PM_{10} > 200\ \mu g/m^3$). Our findings should be understood in the light of the fact that 21% of the population in Kuwait is made up by those under 15 years of age and presence of an easy access to health care in this affluent oil rich nation. Given that during the major dust storm events, schools and educational institutions are officially closed and houses are well sealed and kept closed with a heavy use of air conditioning in Kuwait, one may postulate that even a stronger impact on respiratory and asthma admissions is possible if such practices of avoidance strategies are not adopted. It should be noted, however, that closing schools and issuing formal public warning from dust remain under the discretion of authorities and do not depend on the measured level of dust and hence may apply only on rare occasions.

The impact of dust storms on the risk of admission due to asthma and respiratory diseases has a plausible biological mechanism. Dust particles have been categorized according to their aerodynamic diameter to fine particles less than 2.5 μm ($PM_{2.5}$) and coarse particles which are smaller than 10 μm but larger than 2.5 μm ($PM_{2.5\text{-}10}$). Fine particles are mainly derived from non-natural sources such as combustion of fossil fuel and are of greatest health concern as they penetrate to the deepest parts of the lungs while coarse particles primarily originate from geologic source such as soil and crustal materials. Coarse particles form the predominant portion of dust in dust storms during which fine particles and other air pollutants may decline due high wind speed (Schwartz et al., 1999; Xie et al., 2005). Although coarse particles have been described to be less toxic than fine particles, they had stronger effect in inducing inflammatory mediators (Becker et al., 2003) which are essential in asthma attacks or other respiratory disorders. A scientific review has shown that the impact of coarse particles on asthma and respiratory admissions is stronger than of that of fine particles (Brunekreef and Forsberg, 2005). Experiments on animals have provided further understanding of the association between dust and respiratory symptoms (Ichinose et al., 2008a,2008b; Mancino et al., 1984). One of our findings was that children with asthma are particularly vulnerable to dust storm events. This is in line with a Korean study that showed Asian dust storms to be associated with reduction in pulmonary function of school children particularly among asthmatics (Hong et al., 2010) and other studies which described the impact of Asian dust events on the respiratory symptoms of patients with asthma (Park et al., 2005; Yoo et al., 2008).

Our findings should be interpreted in the light of the limitations associated with the design and analyses of our study. In general, the epidemiological studies to assess the effect of pollution on health could use cross-sectional comparisons across communities or time-series analyses over time in single communities. Time-series analysis, similar to what we have used, offers certain advantages, primarily if the study population is similar over time, so that it acts as its own control. However, modeling such data is complicated by the fact that other environmental factors and other causes of illness can confound the results unless they are adequately addressed. For example, during winter time influenza epidemics cause long-wave peaks in respiratory mortality. Variations in emissions, dispersion, and atmospheric chemistry can cause seasonal cycles in pollution. Such superimposed long-wave noise signals can overwhelm a short-term signal of interest. Moreover, variables such as temperature and season do vary over time and have enormous impacts on hospital admission, making the effects of low levels of pollution much harder to discern. We adjusted for these potential confounders in estimating our effects. Nonetheless, the model specifications can strongly affect the results of a time-series model. One advantage of using the time series design was that generally known life style and behavioral risk factors such as smoking cannot confound the short-term temporal relationships between air pollution and health, as the prevalence of these factors is not thought to vary much on a population-wide basis over short study periods. Time series nature of the study, however, suffers from the assumption that all individuals are exposed to the same level of exposure without accounting for individual characteristics that determine the level of exposure. Finally, our findings have described the short-term impact of dust storms on respiratory admissions but the long-term impact, which is difficult to investigate, remains unknown.

In conclusion, our findings suggest that dust storms events have a significant impact on respiratory admissions. The evidence is more convincing and robust than what was already known. This is extremely important given that the intensity of dust storm exposure is higher in our region with a larger pediatric and younger population with increasing prevalence of asthma and other respiratory conditions.

Acknowledgement

This study was supported by the Kuwait University Research Grant MXS001 that was funded by the Environment Public Authority of Kuwait. The funding body was not involved in the study design; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication. The authors also like to acknowledge the technical assistance provided by Dr Mumtaz Shukkur and Mr Joseph Edison Gomez.

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