Environment International 126 (2019) 476–483

Contents lists available at ScienceDirect

Environment International

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

Acute effects of air pollution on mortality: A 17-year analysis in Kuwait

Souzana Achilleos[a,b,*], Ebaa Al-Ozairi[c,d], Barrak Alahmad[b], Eric Garshick[e,f,g], Andreas M. Neophytou[h], Walid Bouhamra[i], Mohamed F. Yassin[j], Petros Koutrakis[b]

[a] Cyprus International Institute for Environmental and Public Health, Cyprus University of Technology, Limassol, Cyprus
[b] Department of Environmental Health, Harvard T.H. Chan School of Public Health, Harvard University, Boston, MA, USA
[c] Department of Medicine, Faculty of Medicine, Kuwait University, Kuwait City, Kuwait
[d] Dasman Diabetes Institute, Kuwait City, Kuwait
[e] Pulmonary, Allergy, Sleep, and Critical Care Medicine Section, VA Boston Healthcare System, Boston, MA, USA
[f] Channing Division of Network Medicine, Brigham and Women's Hospital, Boston, MA, USA
[g] Harvard Medical School, Boston, MA, USA
[h] Division of Environmental Health Sciences, School of Public Health, University of California, Berkeley, CA, USA
[i] Chemical Engineering Department, Kuwait University, Kuwait City, Kuwait
[j] Environment and Life Sciences Center, Kuwait Institute for Scientific Research (KISR), Kuwait City, Kuwait

ARTICLE INFO

Handling Editor: Xavier Querol

Keywords:
Desert dust
Dust storm
Kuwait
Mortality
Time series

ABSTRACT

Background: The health burden from exposure to air pollution has been studied in many parts of the world. However, there is limited research on the health effects of air quality in arid areas where sand dust is the primary particulate pollution source.
Objective: Study the risk of mortality from exposure to poor air quality days in Kuwait.
Methods: We conducted a time-series analysis using daily visibility as a measure of particulate pollution and non-accidental total mortality from January 2000 through December 2016. A generalized additive Poisson model was used adjusting for time trends, day of week, and temperature. Low visibility (yes/no), defined as visibility lower than the 25th percentile, was used as an indicator of poor air quality days. Dust storm events were also examined. Finally, we examined these associations after stratifying by gender, age group, and nationality (Kuwaitis/non-Kuwaitis).
Results: There were 73,748 deaths from natural causes in Kuwait during the study period. The rate ratio comparing the mortality rate on low visibility days to high visibility days was 1.01 (95% CI: 0.99–1.03). Similar estimates were observed for dust storms (1.02, 95% CI: 1.00–1.04). Higher and statistically significant estimates were observed among non-Kuwaiti men and non-Kuwaiti adolescents and adults.
Conclusion: We observed a higher risk of mortality during days with poor air quality in Kuwait from 2000 through 2016.

1. Introduction

The rapidly increasing rate of economic and urban growth, industrial development, climate change, and arid climatic conditions in Southwest Asia has increased air pollution in the area. Countries in Southwest Asia, along with other Eastern Asian countries, experience the highest rates of mortality due to air pollution (~59% of total global deaths) in the world (Cohen et al., 2017).

Kuwait is among the most polluted countries in Southwest Asia (Barkley et al., 2017). Daily and annual $PM_{2.5}$ and PM_{10} (particulate matter with aerodynamic diameter < 2.5 and 10 µm, respectively) concentration levels in Kuwait substantially exceed the World Health Organization (WHO) ambient air quality standards ($PM_{2.5}$: 10 µg/m^3 annual mean and 25 µg/m^3 24-hr mean; PM_{10}: 20 µg/m^3 annual mean and 50 µg/m^3 24-hr mean) mainly because of the frequent desert dust storms, power plants, petrochemical activity, and traffic emissions (Alolayan et al., 2013; Brown et al., 2008; Draxler et al., 2001; Tsiouri et al., 2015). The deposition of dust attributable to natural and multiple industrial sources in Kuwait (0.6 kg/m^2/year) is ranked first out of 57 dust depositions throughout the world (0.00005–0.45 kg/m^2/year) (Al-

* Corresponding author at: Cyprus International Institute for Environmental and Public Health, Cyprus University of Technology, Limassol, Cyprus.
E-mail address: souzana.achilleos@cut.ac.cy (S. Achilleos).

https://doi.org/10.1016/j.envint.2019.01.072
Received 11 October 2018; Received in revised form 3 January 2019; Accepted 28 January 2019
Available online 04 March 2019

Awadhi and AlShuaibi, 2013). While there are many epidemiological studies on health and air pollution from many areas across the world, there is still little epidemiological data in Southwest Asia countries (Abdo et al., 2016; Goudie, 2014).

Therefore, in this study we aimed to assess the association between exposure to poor air quality and mortality in Kuwait. Unlike the USA and Europe, there is little historical air pollution data available in Kuwait. Therefore, we used visibility as an indicator of ambient air quality. Visibility is inversely associated with air pollution (Masri et al., 2017; Tsai, 2005; Watson, 2002), and has been used as an air pollution metric in epidemiological studies before (Schwartz, 1991; Thach et al., 2010). In this study, we used time-series analysis to explore the association between exposure to poor air quality and acute mortality in Kuwait during the 17-year period from 2000 through 2016. We also examined whether population characteristics (nationality, gender, and age) may modify the effect of air pollution on mortality.

2. Methods

2.1. Study area

Kuwait is a small country (area = 17,818 km^2), located at the tip of the Persian Gulf, between Saudi Arabia and Iraq. It is situated between latitudes 28° and 31° N, and longitudes 46° and 49° E. Most of the country is covered by the Arabian Desert and is surrounded by five major dust sources (southwestern desert of Iraq, the Mesopotamian Flood Plain in Iraq, northeastern desert of Saudi Arabia, drain marshes area in southern Iraq, and dry marshes and abandoned farms in Iran) (Al-Dousari and Al-Awadhi, 2012). For this reason, dust storms are a significant source of pollution in the area (Al-enezi et al., 2014; Alolayan et al., 2013). Kuwait has a subtropical desert climate with dry, intensely hot summers and short, cool winters. Kuwait has a population of ~4.5 million people (~2.8 M males and 1.7 M females), and non-Kuwaitis account for 70% of the population (70% of non-Kuwaitis are males) (PACI, 2017).

2.2. Mortality data

Cause-specific daily number of deaths that had occurred inside Kuwait from 1 January 2000 to 31 December 2016 was obtained from the National Center of Health Information (NCHI) at the Ministry of Health, Kuwait. We examined total non-accidental (ICD-10 codes A00-R99) mortality causes. Information on gender, age, and nationality (Kuwaitis, non-Kuwaitis) of the mortality records was also available.

2.3. Visibility and weather data

Hourly visibility (visual range measurements using Present Weather Detector 22 sensors; PWD22, Vaisala Inc., Louisville, CO; (m)), and temperature (°C) data was obtained for the same study period. The measurements were collected at the Kuwait International Airport by the U.S. Air Force as described in Masri et al. (2017). Missing visibility and weather data were replaced from data collected at other U.S. Air Force stations, located ~45–70 km from the airport (correlation > 0.85). We defined 'low visibility' days the days that visibility dropped below the 25th percentile of the hourly distribution (6000 m) and used it as an indication of poor outdoor air quality (by dust or other source).

Poor visibility days were classified as dust storms if: 1) there was a high aerosol load in the air indicated by high values of Aerosol Optical Depth (AOD, > 0.4) from Moderate Resolution Imaging Spectroradiometer (MODIS) Terra/Aqua Multi-angle Implementation of Atmospheric Correction (MAIAC) Land 1-km data (Lyapustin and Wang, 2018); and 2) dust presence as shown by the corrected reflectance images of MODIS–Terra/Aqua satellite from the NASA Worldview application (https://worldview.earthdata.nasa.gov/), operated by the NASA/Goddard Space Flight Center Earth Science Data and Information System (ESDIS) project, and/or aerosol map images from the BSC-DREAM8b model, operated by the Barcelona Supercomputing Center (http://www.bsc.es/ess/bsc-dust-daily-forecast).

2.4. Statistical analyses

We studied the association between daily mortality and same day exposure to low visibility days using a Poisson regression. We used a generalized additive model (GAM) adjusting for potential confounders (Peng et al., 2006). The model is specified as:

$$\log[E(Y_i)] = \text{intercept} + ns(\text{time}_i, df = 68) + ns(\text{temperature}_i, df = 3) + ns(\text{temperature}_{i-1}, df = 3) + (\text{day of week})_i + \text{visibility}_i \quad (1)$$

where, $E(Y_i)$ is the expected death count at day i, and ns denotes natural cubic regression splines. We accounted for time trends with a natural cubic regression spline of 4 degrees of freedom (df) per year, daily temperature on the same day (lag 0) and on previous day (lag 1) with a natural cubic regression spline (3 df each), day of the week as a categorical variable (1–7, Sunday as the referent day), and an indicator variable for visibility [0: high visibility days, 1: low visibility days]. We assumed a quasi-Poisson distribution to account for over-dispersion in the daily death counts. We also assessed associations after stratifying by gender, age (children: 0–14, adolescents and adults: 15–65, elderly: > 65 years old), and nationality (Kuwaitis/non-Kuwaitis). Finally, a model with an indicator variable for dust storm was also considered.

As a sensitivity analysis, we repeated the analyses: 1) using a 'low visibility' cut point ± 100 m from the threshold that was used in the main analyses, and 2) use 5df and 6 df per year in the spline term for time. Lagged exposure up to six days (lag 0–5) was also examined using a polynomial distributed lag model (DLM) (Schwartz, 2000).

Statistical analyses were performed using R Statistical Software, version 3.4.3 (The R Foundation for Statistical Computing, Vienna, Austria).

3. Results

3.1. Summary statistics

There were 73,748 deaths from non-accidental causes in Kuwait during the period between 2000 and 2016. Table 1 summarizes the daily mortality, visibility and weather parameters. On average, 12 people died every day from non-accidental causes. Daily average visibility ranged between 729 and 14,056 m during the study period. Visibility measurements across the study period are illustrated in Fig. 1. Visibility was lowest during the summer months due to the high frequency of dust storms. More than half of the low visibility days were classified as dust storms (~110 days per year). Mortality rate was similar across the two air quality scenarios. Ambient temperature was higher during dust and low

Table 1
Summary statistics (mean ± SD) of daily mortality, visibility, and temperature (Temp) across Kuwait in 2000–2016.

Variable	All days (n=6,210)	Low visibility days (n=2,929)	High visibility days (n=3,281)	Dust storm days (n=1,609)[b]	Non-dust storm days (n=4,531)[b]
Total[a] mortality (deaths/day)	11.9 ± 4.5	11.9 ± 4.6	11.9 ± 4.5	12.0 ± 4.6	11.9 ± 4.5
Visibility (m)	8,217 ± 1,845	6,890 ± 1,804	9,402 ± 746	6,297 ± 1,829	8,890 ± 1,291
Temp, (°C)	27.1 ± 9.8	27.4 ± 9.8	26.9 ± 9.9	30.1 ± 8.8	26.2 ± 9.9

[a]ICD10 A00-R99.
[b]Restricted to days which AOD data and/or satellite images/aerosol maps was available.

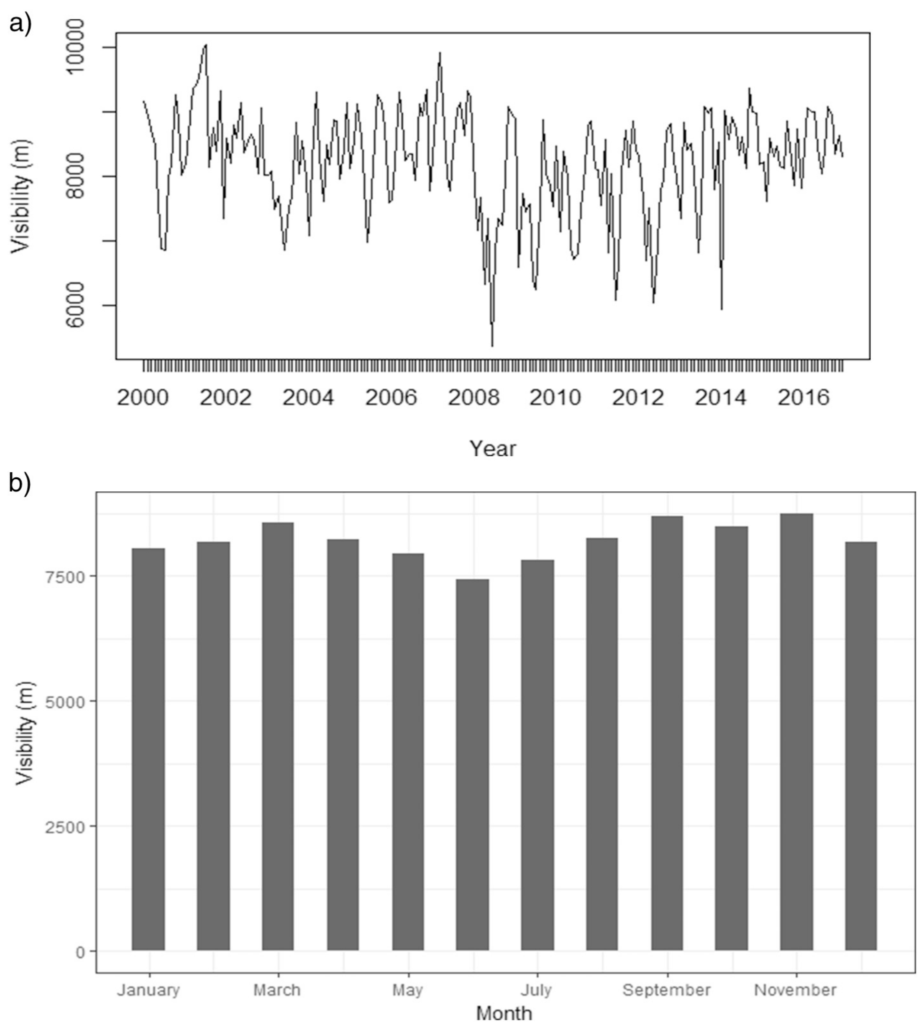

Fig. 1. The monthly visibility average across the study period per year (a), and per month (b).

Table 2
Summary statistics (mean ± SD) of daily total mortality (ICD10 A00-R99) across Kuwait in 2000–2016 by nationality, age group, and gender.

	All days (n=6,210)	Low visibility days (n=2,929)	High visibility days (n=3,281)	Dust storm days (n=1,609)	Non-Dust storm days (n=4,531)
Nationality					
Kuwaitis	6.3 ± 2.9	6. 3 ± 3.0	6. 3 ± 2.9	6.3 ± 3.0	6.4 ± 2.9
Non-Kuwaitis	5.5 ± 2.7	5.6 ± 2.8	5.5 ± 2.8	5.7 ± 2.9	5.5 ± 2.8
Gender					
Males	7.1 ± 3.1	7.1 ± 3.2	7.1 ± 3.1	7.1 ± 3.2	7.1 ± 3.1
Females	4.9 ± 2.5	4.8 ± 2. 6	4.8 ± 2.5	4.8 ± 2.7	4.8 ± 2.5
Age groups					
Children (age 0-14 years)	1.4 ± 1.2	1.4 ± 1.3	1.3 ± 1.2	1.4 ± 1.3	1.4 ± 1.3
Adults (age 15-65years)	5.4 ± 2.7	5.3 ± 2.8	5.4 ± 2.6	5.4 ± 2.7	5.4 ± 2.7
Elderly (65+ years)	5.2 ± 2.7	5.2 ± 2.7	5.2 ± 2.7	5.2 ± 2.7	5.2 ± 2.7
Nationality-Gender					
Kuwaitis-Males	3.4 ± 2.0	3.4 ± 2.0	3.4 ± 2.0	3.3 ± 2.0	3.4 ± 2.0
Kuwaitis-Females	3.0 ± 1.9	3.0 ± 1.9	3.0 ± 1.9	3.0 ± 2.0	3.0 ± 1.9
NonKuwaitis-Males	3.7 ± 2.2	3.7 ± 2.2	3.7 ± 2.2	3.8 ± 2.3	3.7 ± 2.2
NonKuwaitis-Females	1.8 ± 1.5	1.8 ± 1.5	1.8 ± 1.4	1.8 ± 1.5	1.8 ± 1.4
Nationality-Age groups					
Kuwaitis-Children	0.8 ± 0.9	0.8 ± 0.9	0.8 ± 0.9	0.8 ± 0.9	0.8 ± 0.9
Kuwaitis-Adults	2.1 ± 1.5	2.1 ± 1.5	2.1 ± 1.5	2.0 ± 1.5	2.1 ± 1.5
Kuwaitis-Elderly	3.5 ± 2.1	3.5 ± 2.1	3.5 ± 2.1	3.5 ± 2.2	3.5 ± 2.1
NonKuwaitis-Children	0.6 ± 0.8	0.6 ± 0.8	0.6 ± 0.8	0.6 ± 0.8	0.6 ± 0.8
NonKuwaitis-Adults	3.3 ± 2.0	3.3 ± 2.1	3.3 ± 2.0	3.4 ± 2.1	3.3 ± 2.0
NonKuwaitis-Elderly	1.7 ± 1.4	1.7 ± 1.4	1.7 ± 1.4	1.7 ± 1.4	1.7 ± 1.4

visibility days.

Table 2 presents daily mortality by nationality, gender, and age groups. Between 2000 and 2016, 39,389 Kuwaitis and 34,359 non-Kuwaitis died from all-causes in Kuwait. Among them, 43,898 people were males (20,944 Kuwaitis and 22,954 non-Kuwaitis) and 29,850 were females (18,445 Kuwaitis and 11,405 non-Kuwaitis). The number of deaths by age group was: 8454 children (4781 Kuwaitis and 3673 non-Kuwaitis); 33,250 adolescents/adults (12,938 Kuwaitis and 20,312 non-Kuwaitis); and 32,044 elderly (21,670 Kuwaitis and 10,374 non-Kuwaitis). Total non-accidental daily death counts were higher during low visibility and dust storm days among non-Kuwaitis.

3.2. Mortality effect estimates

Table 3 presents the rate ratio (RR) comparing mortality rates on low-visibility/dust days to mortality rates on high-visibility/non-dust days. Statistically significant association at 0.05 level was found between exposure to dust storms and mortality among non-Kuwaitis (RR = 1.04; 95% CI: 1.00, 1.06), and non-Kuwaiti men (RR = 1.05; 95% CI: 1.02, 1.09). The results are still suggestive but not statistically significant at 0.05 significance level among non-Kuwaitis (RR = 1.02; 95% CI: 1.00, 1.05) and non-Kuwaiti males (RR = 1.03; 95% CI: 1.00, 1.06) during low visibility days, and among non-Kuwaiti adolescences and adults (RR = 1.04; 95% CI: 1.00, 1.07) during dust storm days. Mortality effect estimates were found to be similar when low visibility cut point changed by 100 m (Table S1). However, when increasing the df for the term for time (5 df/year and 6 df/year) led to the confidence interval for some of the results to include the null (results not shown).

We also examined six days (0–5) single and cumulative lag effect using DLM. Figs. 2–3 show the rate ratio of mortality from 0 to 5 lag day, and the 6-day cumulative effect. A higher mortality rate at lag 1 was found among Kuwaiti children (RR = 1.08, 95% CI: 1.00, 1.17) and at lag 2 among Kuwaiti men (RR = 1.03, 95% CI: 1.00, 1.05) during dust storms.

Table 3
Estimated rate ratio (95% CI) comparing total mortality rates on low visibility days to mortality rates on high visibility days (lag 0) for Kuwait during the study period 2000–2016.

	Exposure scenario	
	Low *versus* high visibility days	Dust *versus* non-dust days
All	1.01 (0.99,1.03)	1.02 (1.00,1.04)
Kuwaitis	1.00 (0.98,1.03)	1.00 (0.98,1.03)
Non-Kuwaitis	1.02 (1.00,1.05) †	1.04 (1.00,1.06) ‡
Males	1.01 (0.99,1.03)	1.02 (1.00,1.05) †
Females	1.01 (0.99,1.04)	1.01 (0.98,1.04)
Children	1.03 (0.98,1.08)	1.00 (0.95,1.06)
Adults	1.00 (0.98,1.03)	1.01 (0.99,1.04)
Elderly	1.01 (0.99,1.04)	1.02 (0.99,1.05)
Kuwaitis-Males	0.99 (0.96, 1.02)	0.99 (0.96,1.03)
Kuwaitis-Females	1.02 (0.98, 1.05)	1.02 (0.98,1.06)
NonKuwaitis-Males	1.03 (1.00,1.06) †	1.05 (1.02,1.09) ‡
NonKuwaitis-Females	1.01 (0.97,1.05)	0.99 (0.94,1.04)
Kuwaitis-Children	1.03 (0.97,1.09)	0.98 (0.91,1.05)
Kuwaitis-Adults	0.99 (0.95,1.03)	0.99 (0.94,1.03)
Kuwaitis-Elderly	1.01 (0.98,1.04)	1.02 (0.99,1.06)
NonKuwaitis-Children	1.04 (0.96,1.11)	1.04 (0.96,1.13)
NonKuwaitis-Adults	1.02 (0.99,1.05)	1.04 (1.00,1.07) †
NonKuwaitis-Elderly	1.03 (0.99,1.07)	1.02 (0.97,1.07)

4. Discussion

In this study, we examined whether exposure to poor air quality, using poor visibility as a proxy due to the lack of daily long term air pollution data, in Kuwait is associated with higher mortality from 2000 through 2016.

We observed an increase in mortality rates associated with exposure to low visibility and dust storms. Half of the days with poor visibility were due to dust storms. Other phenomena such as resuspension of local dust, weather phenomena (*e.g.*, fog), and heavy anthropogenic pollution (*e.g.*, haze, smog) could have also contributed to reduced visibility.

Air quality, as measured by visibility, was significantly associated with mortality in previous studies in Asia (Kumar et al., 2010; Liu et al., 2014). The acute health effects of dust storms have been studied in different parts of the world. Positive associations with total and cardiovascular mortality were found with North American dust in the USA (Crooks et al., 2016); Asian dust in Taiwan and Seoul (Chan and Ng, 2011; Kim et al., 2012; Kwon et al., 2002; Lai, 2014); Saharan dust in Spain and Italy (Diaz et al., 2017; Mallone et al., 2011); Arabian and Saharan dust in Cyprus (Middleton et al., 2008; Neophytou et al., 2013); and Australian dust in Sydney (Merrifield et al., 2013). However, despite the frequent occurrence of dust storms in the Southwest Asia area, the related health effects have not been well documented. To our knowledge, there are only two epidemiological studies of the same authors that examined the acute health effects of dust storms in Kuwait (Al-Taiar and Thalib, 2014; Thalib and Al-Taiar, 2012) and one in Israel (Vodonos et al., 2015). The analyses for Kuwait used five-year data and dust storm days were classified based on PM_{10} concentration data with a cut-off point of 200 μg/m^3. Statistically significant associations were found between dust events and same-day respiratory and asthma admissions, but not with mortality, even when using higher PM concentration cut points. The study in Israel used ten years of PM_{10} and cardiovascular morbidity data. The PM_{10} concentration threshold value used there was 71 μg/m^3 which corresponded to two standard deviations above the background value, and dust days were validated based on back-trajectories and synoptic conditions. Dust storm days were significantly associated with hospital admissions from acute coronary syndrome at lag 0, and with PM_{10} during dust storm days at lag 1.

In our analyses, we also assessed associations by nationality, gender, and age. The rate ratio of dying from exposure to low visibility days and dust storms was higher for non-Kuwaitis, non-Kuwaiti men and non-Kuwaiti adults. Most of the mortality rate ratios for the Kuwaitis and elderly were above one, with Kuwaiti women to be in higher risk, but not statistically significant. The effects for Kuwaitis are not as strong as for non-Kuwaitis, who seemed to be more susceptible, but there is still some effect. This could be due to the high exposure heterogeneity among the population. Even though non-Kuwaitis account for ~70% of the total population in Kuwait, there were more Kuwaiti deaths recorded. The non-Kuwaitis are mostly men and younger with a higher labor employment rate at non-government sectors (construction, agriculture, fishery, craft and related trades, monitor production, etc.) and as domestic servants, and they are therefore more likely to be exposed outdoors (PACI, 2017). There were also more male deaths than female deaths recorded. There are more men than women living in Kuwait (63% of the total population are males), and men, especially non-Kuwaiti men, tend to spend more time outdoors for work and other activities. The main occupation for non-Kuwaiti women in Kuwait is mostly domestic either as servants or housewives (PACI, 2017).

Our study has some important limitations. We used only visibility and no pollution data such as $PM_{2.5}$ or PM_{10} to characterize the air quality in Kuwait. Exposure error was also introduced since we used ambient data from one fixed station assuming that people are exposed to the same ambient average level without indoor sources (Berkson error). Exposure error (classical measurement error and Berkson error) may result in attenuated effect estimates with higher variance (Zeger et al., 2000). However, visibility data was available in daily basis for quite a few years and that increased the power of our study and avoided the bias in the estimates from missing exposure data (Kim et al., 2013; Klemm et al., 2011). In addition, since we did not examine the association between air pollution levels and mortality, but air quality conditions and mortality, we expect a non-significant bias in our estimates.

The strength of this study relies on the health effects analysis of a long term air quality data for the first time in the Southwest Asia. While most of air pollution epidemiological studies are using 10 years of data or less to examine the association between air pollution and mortality, we were able to use 17 years of mortality data and produce robust

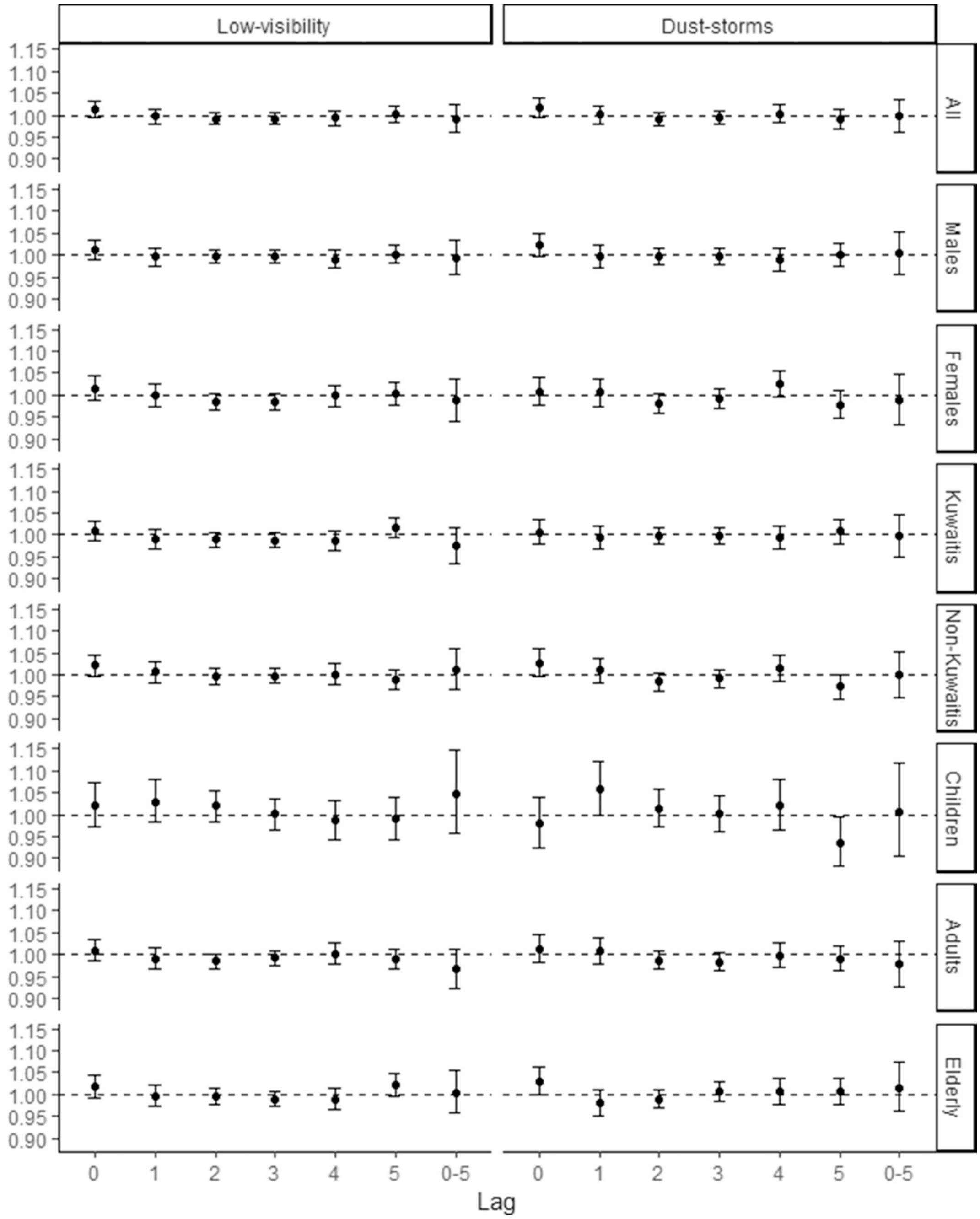

Fig. 2. Estimated rate ratio (95% CI) comparing total mortality rates by nationality and gender for Kuwait during the study period 2000–2016.

estimates. Moreover, we were able to assess the effect modification of population characteristics, especially nationality, on the association between air pollution and mortality since non-Kuwaitis represent more than two-thirds of the population.

In conclusion, exposure to poor air quality conditions was associated with an increased risk of total non-accidental mortality. It appears that nationality, gender and age are potential effect modifiers with non-Kuwaiti males and adults being more vulnerable. Further research is needed to improve the exposure assessment and study the association between indoor and outdoor exposure to specific air pollutants on people's health in areas such as Kuwait that are highly impacted from dust storms and anthropogenic pollution.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2019.01.072.

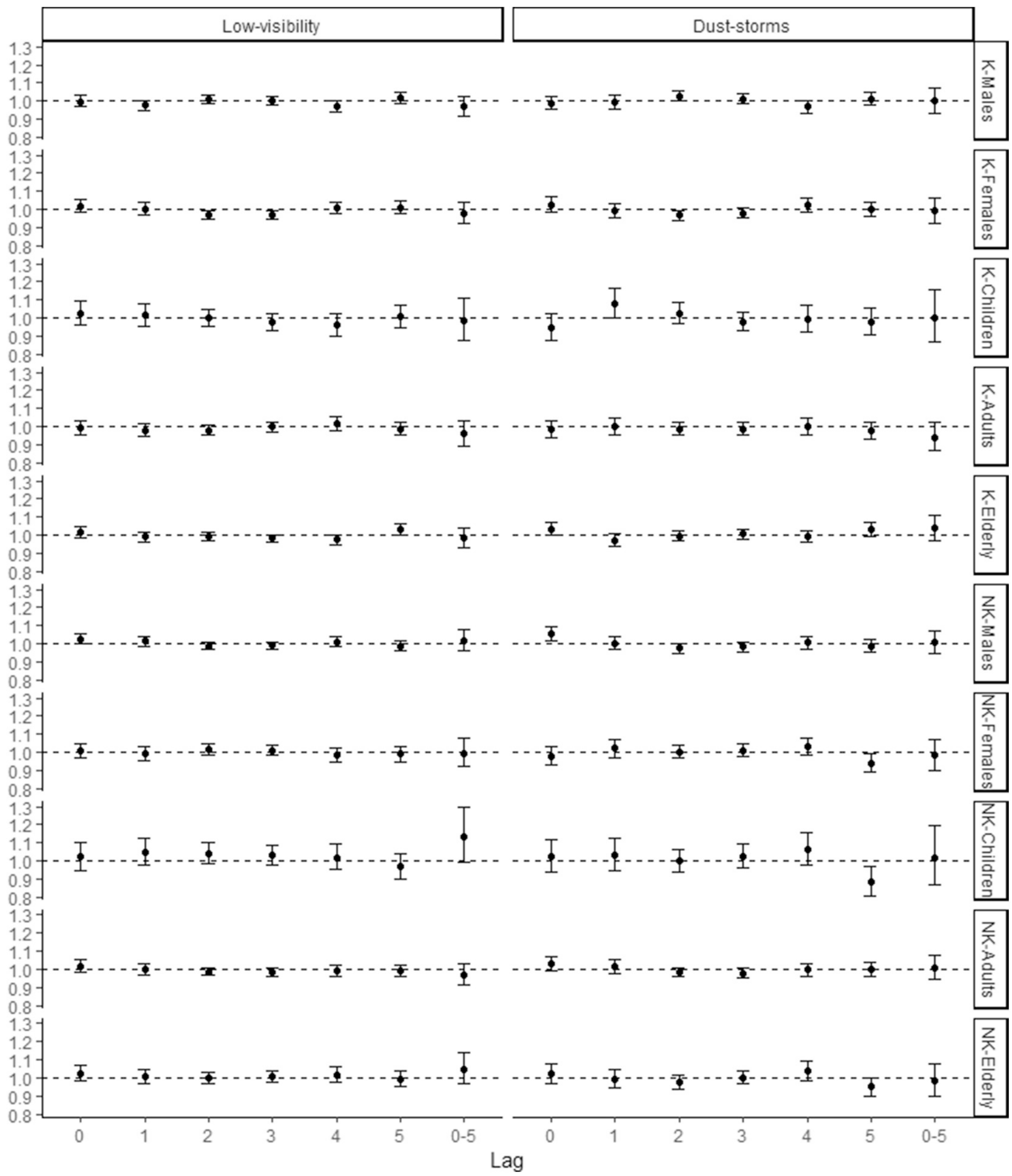

Fig. 3. Estimated rate ratio (95% CI) comparing total mortality rates by combined nationality (K: Kuwaiti, NK: Non-Kuwaiti) and gender/age for Kuwait during the study period 2000–2016.

Acknowledgements

Dr. Souzana Achilleos postdoctoral fellowship at the Harvard T. H. Chan School of Public Health and at the Cyprus University of Technology, was supported by the A.G. Leventis Foundation and Harvard Cyprus Initiative, and by the European Union within the framework of the LIFE Program under the Grant Agreement LIFE16 CCA/CY/000041, respectively. Dr. E. Garshick's contributions to this work were partially supported by VA Cooperative Studies Program #595: Pulmonary Health and Deployment to Southwest Asia and Afghanistan, from the United States Department of Veterans Affairs, Office of Research and Development, Clinical Sciences Research and Development, Cooperative Studies Program. The views expressed in this article are those of the authors and do not necessarily represent the position or policy of the Department of Veterans Affairs or the United States Government. This publication was also made possible by United States Environmental Protection Agency (US EPA) grant RD-835872-01. Its contents are solely the responsibility of the grantee and do not necessarily represent the official views of the USEPA. Further, USEPA does not endorse the purchase of any commercial products or services mentioned in the publication.

The authors appreciate the assistance of Mike Hunsucker and Jeff Zautner, 14th Weather Squadron (U.S. Air Force), Asheville, NC, for assistance with the Kuwait visibility data. We also want to thank Dr. Jing Li for downloading and providing AOD data.

References

Abdo, N., Khader, Y.S., Abdelrahman, M., Graboski-Bauer, A., Malkawi, M., Al-Sharif, M., et al., 2016. Respiratory health outcomes and air pollution in the eastern Mediterranean region: a systematic review. Rev. Environ. Health 31, 259–280.

Al-Awadhi, J.M., AlShuaibi, A.A., 2013. Dust fallout in Kuwait city: deposition and characterization. Sci. Total Environ. 461-462, 139–148.

Al-Dousari, A.M., Al-Awadhi, J., 2012. Dust fallout in northern Kuwait, major sources and characteristics. Kuwait J. Sci. 39, 171–187.

Al-enezi, E., Al-dousari, A., Al-shammari, F., 2014. Modeling adsorption of inorganic phosphorus on dust fallout in Kuwait bay. J. Eng. Res. 2, 1.

Alolayan, M.A., Brown, K.W., Evans, J.S., Bouhamra, W.S., Koutrakis, P., 2013. Source

apportionment of fine particles in Kuwait City. Sci. Total Environ. 448, 14–25.
Al-Taiar, A., Thalib, L., 2014. Short-term effect of dust storms on the risk of mortality due to respiratory, cardiovascular and all-causes in Kuwait. Int. J. Biometeorol. 58, 69–77.
Barkley, M.P., González Abad, G., Kurosu, T.P., Spurr, R., Torbatian, S., Lerot, C., 2017. Omi air-quality monitoring over the middle east. Atmos. Chem. Phys. 17, 4687–4709.
Brown, K.W., Bouhamra, W., Lamoureux, D.P., Evans, J.S., Koutrakis, P., 2008. Characterization of particulate matter for three sites in Kuwait. J. Air Waste Manag. Assoc. 58, 994–1003.
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. Sci. Total Environ. 410-411, 47–52.
Cohen, A.J., Brauer, M., Burnett, R., Anderson, H.R., Frostad, J., Estep, K., et al., 2017. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the global burden of diseases study 2015. Lancet 389, 1907–1918.
Crooks, J.L., Cascio, W.E., Percy, M.S., Reyes, J., Neas, L.M., Hilborn, E.D., 2016. The association between dust storms and daily non-accidental mortality in the United States, 1993–2005. Environ. Health Perspect. 124, 1735–1743.
Diaz, J., Linares, C., Carmona, R., Russo, A., Ortiz, C., Salvador, P., et al., 2017. Saharan dust intrusions in Spain: health impacts and associated synoptic conditions. Environ. Res. 156, 455–467.
Draxler, R.R., Gillette, D.A., Kirkpatrick, J.S., Heller, J., 2001. Estimating pm10 air concentrations from dust storms in Iraq, Kuwait and Saudi Arabia. Atmos. Environ. 35, 4315–4330.
Goudie, A.S., 2014. Desert dust and human health disorders. Environ. Int. 63, 101–113.
Kim, H.S., Kim, D.S., Kim, H., Yi, S.M., 2012. Relationship between mortality and fine particles during Asian dust, smog-Asian dust, and smog days in Korea. Int. J. Environ. Health Res. 22, 518–530.
Kim, S.Y., Sheppard, L., Hannigan, M.P., Dutton, S.J., Peel, J.L., Clark, M.L., et al., 2013. The sensitivity of health effect estimates from time-series studies to fine particulate matter component sampling schedule. J. Expo. Sci. Environ. Epidemiol. 23, 481–486.
Klemm, R.J., Thomas, E.L., Wyzga, R.E., 2011. The impact of frequency and duration of air quality monitoring: Atlanta, ga, data modeling of air pollution and mortality. J. Air Waste Manag. Assoc. 61, 1281–1291.
Kumar, R., Sharma, S.K., Thakur, J.S., Lakshmi, P.V., Sharma, M.K., Singh, T., 2010. Association of air pollution and mortality in the Ludhiana city of India: a time-series study. Indian J. Public Health 54, 98–103.
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. Environ. Res. 90, 1–5.
Lai, L.W., 2014. Relationship between fine particulate matter events with respect to synoptic weather patterns and the implications for circulatory and respiratory disease in Taipei, Taiwan. Int. J. Environ. Health Res. 24, 528–545.
Liu, T., Zhang, Y.H., Xu, Y.J., Lin, H.L., Xu, X.J., Luo, Y., et al., 2014. The effects of dust-haze on mortality are modified by seasons and individual characteristics in Guangzhou, China. Environ. Pollut. 187, 116–123.
Lyapustin, A., Wang, Y., 2018. MCD19A2 MODIS/Terra + Aqua Land Aerosol Optical Depth Daily L2G Global 1km SIN Grid V006 [Data set]. NASA EOSDIS Land Processes DAAChttps://doi.org/10.5067/MODIS/MCD19A2.006.
Mallone, S., Stafoggia, M., Faustini, A., Gobbi, G.P., Marconi, A., Forastiere, F., 2011. Saharan dust and associations between particulate matter and daily mortality in Rome, Italy. Environ. Health Perspect. 119, 1409–1414.
Masri, S., Garshick, E., Hart, J., Bouhamra, W., Koutrakis, P., 2017. Use of visual range measurements to predict fine particulate matter exposures in southwest Asia and Afghanistan. J. Air Waste Manage. Assoc. 67, 75–85.
Merrifield, A., Schindeler, S., Jalaludin, B., Smith, W., 2013. Health effects of the September 2009 dust storm in Sydney, Australia: did emergency department visits and hospital admissions increase? Environ. Health 12, 32.
Middleton, N., Yiallouros, P., Kleanthous, S., Kolokotroni, O., Schwartz, J., Dockery, D.W., et al., 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. Environ. Health 7, 39.
Neophytou, A.M., Yiallouros, P., Coull, B.A., Kleanthous, S., Pavlou, P., Pashiardis, S., et al., 2013. Particulate matter concentrations during desert dust outbreaks and daily mortality in Nicosia, Cyprus. J. Expo. Sci. Environ. Epidemiol. 23, 275–280.
PACI, 2017. The Public Authority for Civil Information. Government of Kuwait.
Peng, R.D., Dominici, F., Louis, T.A., 2006. Model choice in time series studies of air pollution and mortality. J. R. Stat. Soc. A. Stat. Soc. 169, 179–203.
Schwartz, J., 1991. Particulate air pollution and daily mortality in Detroit. Environ. Res. 56, 204–213.
Schwartz, J., 2000. The distributed lag between air pollution and daily deaths. Epidemiology 11, 320–326.
Thach, T.-Q., Wong, C.-M., Chan, K.-P., Chau, Y.-K., Chung, Y.-N., Ou, C.-Q., et al., 2010. Daily visibility and mortality: assessment of health benefits from improved visibility in Hong Kong. Environ. Res. 110, 617–623.
Thalib, L., Al-Taiar, A., 2012. Dust storms and the risk of asthma admissions to hospitals in Kuwait. Sci. Total Environ. 433, 347–351.
Tsai, Y.I., 2005. Atmospheric visibility trends in an urban area in Taiwan 1961–2003. Atmos. Environ. 39, 5555–5567.
Tsiouri, V., Kakosimos, K.E., Kumar, P., 2015. Concentrations, sources and exposure risks associated with particulate matter in the middle east area—a review. Air Qual. Atmos. Health 8, 67–80.
Vodonos, A., Friger, M., Katra, I., Krasnov, H., Zahger, D., Schwartz, J., et al., 2015. Individual effect modifiers of dust exposure effect on cardiovascular morbidity. PLoS One 10, e0137714.
Watson, J.G., 2002. Visibility: science and regulation. J. Air Waste Manage. Assoc. 52, 628–713.
Zeger, S.L., Thomas, D., Dominici, F., Samet, J.M., Schwartz, J., Dockery, D., et al., 2000. Exposure measurement error in time-series studies of air pollution: concepts and consequences. Environ. Health Perspect. 108, 419–426.