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ABSTRACT

BACKGROUND: Despite the fact that Iran has been exposed to severe dust storms during the past 2 decades, few studies have investigated the health effects of these events in Iran. This study was conducted to assess the association between dust storms and daily non-accidental, cardiovascular, and respiratory mortality in Dezful City (Khuzestan Province, Iran) during 2014 to 2019.

METHODS: In this study, mortality, meteorological, and climatological data were obtained from the Dezful University of Medical Sciences, Iranian Meteorological Organization, and Department of Environment in Khuzestan Province, respectively. Days of dust storm were identified based on the daily concentration threshold of particulate matter with an aerodynamic diameter of less than 10 µm (PM_{10}) according to Hoffmanns¯definition, and then an ecological time-series was used to estimate the short-term effects of dust storms on daily mortality. Statistical analysis was performed using a distributed lag linear model (DLM) and a distributed lag non-linear model (DLNM) packages by R software and the study results were reported as excess mortality.

RESULTS: During the study period, 15 223 deaths were recorded, and 139 dust storms occurred in Dezful city. In addition, there was statistically significant excess risk of mortality due to dust storms in Dezful City (mortality in the group under 15 years of age, lag_4: 34.17% and 15-64 years of age groups, lag_5: 32.19%, lag_6: 3.28%), also dust storms had statistically significant effects on respiratory mortality (lag_6: 5.49%).

CONCLUSION: The findings of the current study indicate that dust storms increase the risk of mortality with some lags. An evidence-based early warning system may be able to aware the people of the health effects of dust storms.

KEYWORDS: Mortality, dust storm, Middle East, health, time series

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Introduction

Adverse outcomes of air pollution on humans' health have been already recognized.[1-7] Inhalation of environmental particles suspended in the ambient air can cause many side effects on public health and welfare of residents in the affected areas.[8,9] Particulate matter (PM) in dust storms is one of the important sources of air pollutions transmitting from desert or arid areas.[10] Dust storms can transfer PMs from remote arid regions and desert areas to residential areas,[11,12] and extend concentration of atmospheric PM in residential areas to several times more than the health standards.[12,13] Due to their small size, these particles enter the respiratory tract[14] and when they enter the lungs, they can cause local damage as well as subsequent systematic damages to other parts of the body including heart and brain.[5,6] In addition, dust storms can influence humans' health and increase mortality and morbidity through interacting with microscopic organisms, such as fungi and bacteria[6] and inhalable metal elements transferred in storms.[15,16]

According to the United States environmental protection agency (EPA), long and short-term exposure to environmental particles from dust storms could have devastating effects on humans' health.[17] Because the chemical composition of the dusts and their sources, concentration of pollutants, and duration of the presence of pollutants in the atmosphere vary in different areas, the health effects of dust storms may vary from a place to another place.[1,8,9,18,19] While some studies have reported that dust storms had no adverse effects on health,[20,21] the adverse health effects of air pollution caused by dust storms and their PMs have been supported by numerous studies.[1,8,9,18,19,22,23] Crooks et al[24] reported that dust storms significantly increased the risk of non-accidental death in the USA. In addition, Díaz et al[25] found that PM on days with dust storms is significantly associated with daily mortality. Moreover, Shahsavani et al,[12] Khaniabadi et al,[26] and Goudarzi et al[27] in several studies conducted in Iran (Ahvaz, Khorramabad, and Kermanshah, respectively) stated that increasing concentration of PM during Middle Eastern dust storms had a significant effect on mortality and morbidity.

In the last decades, number of dust events have increased,[24] and studies have reported that annually, dust storms affect many different parts of the world including the Middle East, Central and East Asia, North Africa, Southern Europe, Australia, and Western America.[6] Various studies have investigated the short-term effects of dust storms on health at different countries including East Asian and European countries as well as the USA.[5,6] During the last 2 decade, dust storms have frequently occurred at a very severe level of particulate matters in some countries of the Middle East,[12,26,28] however, up until now only few research has been done on the effects of dust storms on humans' health in this region.[6] While, the Middle Eastern countries, particularly Iraq, Syria, and Saudi Arabia have become the epicenter of large and intense dust storms during the recent years, and in addition to exposing themselves to health risks, they can deliver dust particles at very high concentrations (sometimes 10 times the permissible limit) to other countries in the region including Iran.[12,26,27,29,30] Therefore, dust storms have caused widespread health concerns among the people in Iran and other countries.[2-6,27,31,32]

In Iran, some western and southern provinces of the country have been facing with dust storm s for many years. Khuzestan Province, located in southwest of Iran has been facing with a serious dust phenomenon since 2000.[33-35] The average levels of PM_{10} (particulate matter with an aerodynamic diameter less than 10 μm) in Khuzestan Province[36] and Dezful City, has been frequently above the standard levels.[33] Dezful City is the second city (after Omidieh) suffering from dust storms in the last 2 decades in Khuzestan Province (on average, more than 84 days per year between 2002 and 2015), however in terms of population, it is categorized as the most populated city exposed to the highest amount of PM_{10} from dust storms.[33] Dezful City is not an industrial city and thus the PMs in dust storms are less polluted by chemicals compared with other cities in the province. Therefore, this study is the first study that examines the effect of dust storms on mortality (daily non-accidental, cardiovascular, and respiratory mortality) in Southwestern Iran for the city of Dezful.

Materials and Methods

Study area

Dezful City is located in plains of Khuzestan Province in southwest of Iran (Figure 1), and it is 30th populated city in Iran (443 971 people), with an area of nearly 40 km^2.[30] Dezful City, like most cities in the Khuzestan Province has a warm climate with a very hot summer and a Mediterranean winter. It is located 140 m above the sea level. Mean annual rainfall in Dezful is equal to 400 mm, Absolute minimum temperature is equal to −3°C and Absolute maximum temperature is equal to 51.8°C.[37] Also, mean annual humidity, maximum, minimum, and mean temperature, and air pressure in the city is about 50.3%, 32.3°C, 16.3°C, 24.3°C, and 998.5 mmHg, respectively.[37,38] Dust storms in Dezful likely appear from Iraq and Saudi Arabian deserts which dried the lake beds, and sometimes from domestic deserts and dried the lake beds in Khuzestan providence.[32,39]

Data

Data on total daily non-accidental death (NAD) (International Classification of Diseases-10th revision/ICD-10 A00-R99), cardiovascular death (CVD) (ICD-10: I00-I99), and respiratory death (RD) (ICD-10: J00-J99) for Dezful City were obtained from the Iranian death registry by the Deputy of Health at the Dezful University of Medical Sciences during 2014 to 2019. Subsequently, all daily non-accidental mortality cases were classified according to age (under 15, 15-64, 65-74, and 75 years of age and older) and gender.

Meteorological data were obtained from the Islamic Republic of Iran Meteorological Organization (IRIMO). Data on daily maximum, minimum, and mean air temperatures (°C), relative humidity (%), Visibility (m), and wind speed (m/s) were obtained from the weather stations located at the airports of Dezful City. Data on hourly and daily average (24-hours) PM_{10} concentrations were obtained from the Khuzestan Department of Environment. There is one air pollution measurement station in Dezful City and PM concentrations are measured based on the β-ray absorption (locations are provided in the Supplementary Material). Visibility (m) and PM_{10} (μg/m^3) range were used from the Hoffmanns' classification, in order to distinguish dust storm days from non-dust storm ones (Visibility [m] $<$ 2000 and $PM_{10} > 200$) and non-dust storm (Visibility [m] $>$ 2000 and $PM_{10} < 200$) days (Table 1).[40,41]

According to the WHO, for air pollutant, at least 75% of the measurement days must have valid data.[42,43] In this regard, at first, the initial processing and filtering were performed in excel software to remove invalid days and only valid days were included in the present study based on the United States Environmental Protection Agency standard range for air

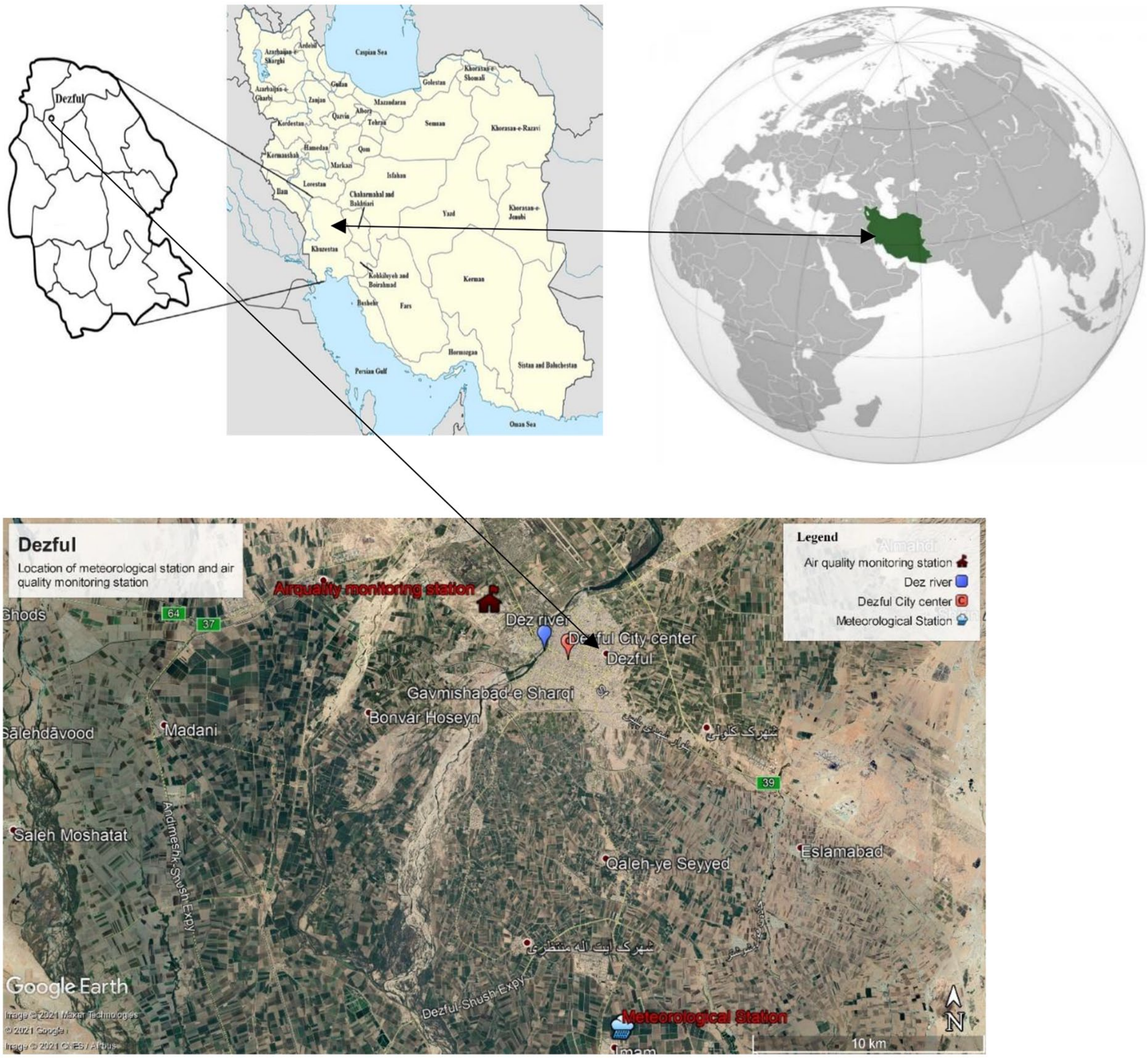


Figure 1. Location of air quality monitoring and meteorological station in Dezful and geographic status of this city in Iran and world.

Table 1. Classification of dust based on visibility, wind speed, and PM_{10} mass concentration.

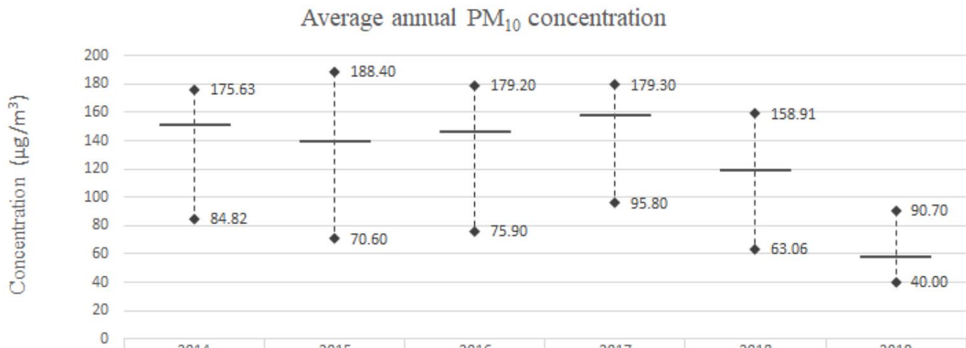
CATEGORY	VISIBILITY (M)	WIND SPEED (M/S)	PM_{10} RANGE (μG/M³)
Dusty air (DA)	Haze	—	50-200
Light dust storm (DS1)	<2000	—	200-500
Dust storm (DS2)	<1000	>17	500-2000
Strong dust storm (DS3)	<200	>20	2000-5000
Serious strong dust storm (DS4)	<50	>25	>5000

pollutant.[44] Also, all the variables were assessed for missing data and expectation-maximization algorithm method was used to impute missing data.[45] In the meteorological data, no missing data were found but in the environmental data, about 5.2% missing data were observed that was acceptable according to the WHO guidelines.[23]

To investigate the effect of Middle Eastern dust storms (MED) on death, the MED effect was divided into 3 general categories: main effect (M); intensified effect (I); and serious intensified effect (SI).

To calculate the main effect, the risk of death at the median PM_{10} during DS days was calculated relative to the risk of death at the median PM_{10} during non-DS days. Since DS happened in all months, in order to calculate the intensified effect and serious intensified effect, the risk of death at 75th and 90th percentile of PM_{10} during the DS was calculated relative to the risk of death at median PM_{10} in non-DS days, respectively.

This method (calculating the main, intensified, and serious intensified effects), allows measuring the added risk of high concentration of PM_{10} on mortality in different lags. A binary variable was constructed, in which code 1 was assigned to DS days and 0 to non-DS days. We used Cumulative Excess Risk



	2014	2015	2016	2017	2018	2019
Average	151.13	139.91	147.05	158.8	119.27	57.95
Percentile 75	175.63	188.40	179.20	179.30	158.91	90.70
Percentile 25	84.82	70.60	75.90	95.80	63.06	40.00

Figure 2. Average annual PM_{10} concentration in Dezful during 2014 to 2019.

(CER) and Excess Risk (ER) to calculate DS effect on mortality according to the equation (1) below.

$$\text{Excess Risk}(\text{ER}) = (\text{Relative Risk } (\text{RR}) - 1) * 100(20) \quad (1)$$

According to a similar previous study, a maximum of 7 lags was chosen to monitor the effect of PM_{10} on death and to determine the full effect of DS on death.[20] The following model was used for statistical analysis.

$$\text{LogE}[Y_t] = \alpha + \text{DS} + \text{cb}(PM_{10}, 4) + \text{cb}(T_m, 2, 2) + \text{ns}(\text{RH}, 3) + \text{ns}(\text{time}, 6) + \text{DOW} + \text{holidays}(20).$$

Where Y_t is the number of deaths observed per day, DS is the indicator variable for dust storms, cb is the cross-basis, DOW is the Day of Week. A DLM matrix was created for PM_{10} with linear function for variable and DS with 4 degrees of freedom (df) for lag. Also, Distributed Lag Non-Linear Models (DLNM) matrix were created for temperature effects with 2 df for variable and 2 df for the lags. The effect of season and time trend were controlled by (6× year) df, the effects of days of week and holidays were included as categorical variables. The function was Natural Spline (NS) for the lags and variables. NS with 3 degrees of freedom was used to control the confounding effects of Relative Humidity (RH). Because the concentration of PM_{10} may vary on different days of the week and on holidays, the effect of weekdays and holidays were included in the model and their effects were adjusted.[20,41]

Degrees of freedom of the variables and lags were calculated based on the lowest quasi-Akaike information criterion (QAIC) value. Previous studies have shown that the relationship between dust storms and death differs based on age and gender.[20,41]

Since the dependent variable of the statistical model has a quasi-Poisson distribution, the Poisson regression model was chosen. The main condition for using this model is equality of variances and means. In practical cases, if the condition is not met and over-dispersion (where the variance is greater than the mean) occurs, then quasi-Poisson model is used. In this study, the quasi-Poisson model was used due to the over-dispersion. Because the number of deaths had a quasi-Poisson distribution, a combination of quasi-Poisson and distributed lag linear model (DLM) was used to analyze the data to determine the effect of PM_{10} on total mortality and different mortality subgroups. The relationships between dust storms and the subgroups including non-accidental, respiratory, and cardiovascular death, male, female, and different age groups were examined. Distributed lag non-linear model (DLNM) version 2.3.5 and R software (version 4.3) were used for data analysis.[46,47]

Results

Descriptive results

According to the Hoffmann definition, during the study period, 14.9% of days were affected by dust storms (274 days from 1833 days). Mean PM_{10} daily average concentrations during the dust storms days was 4.2-fold higher than non-dust storms days (431.1 and 101.5 μg/m³). Overall, 1621 days (88.43) exceeded the WHO threshold for PM_{10} daily average (24-hours) of 50 μg/m³.[48-50] Also, the daily average of PM_{10} during the study period was 129 μg/m³ and the highest hourly average of PM_{10} during the study was 9644 μg/m³. The results regarding average annual concentrations of PM_{10} in ambient air, average monthly relative humidity, temperature, visibility, and PM10 in Dezful City during 2014 to 2019 are presented in Figures 2 and 3. Also, the number of non-accidental death between May 2014 and May 2019, was 15 223, of which the majority were male (8743). More details on population, meteorology, and mortality information are presented in Table 2.

Middle eastern dust storms (MED) effects in Dezful city

The models were adjusted for trend, seasonality, temperature, relative humidity, weekdays, and holidays. In the present study, excess mortality was found to be significantly related in some lags with the main effect, intensified effect, and serious

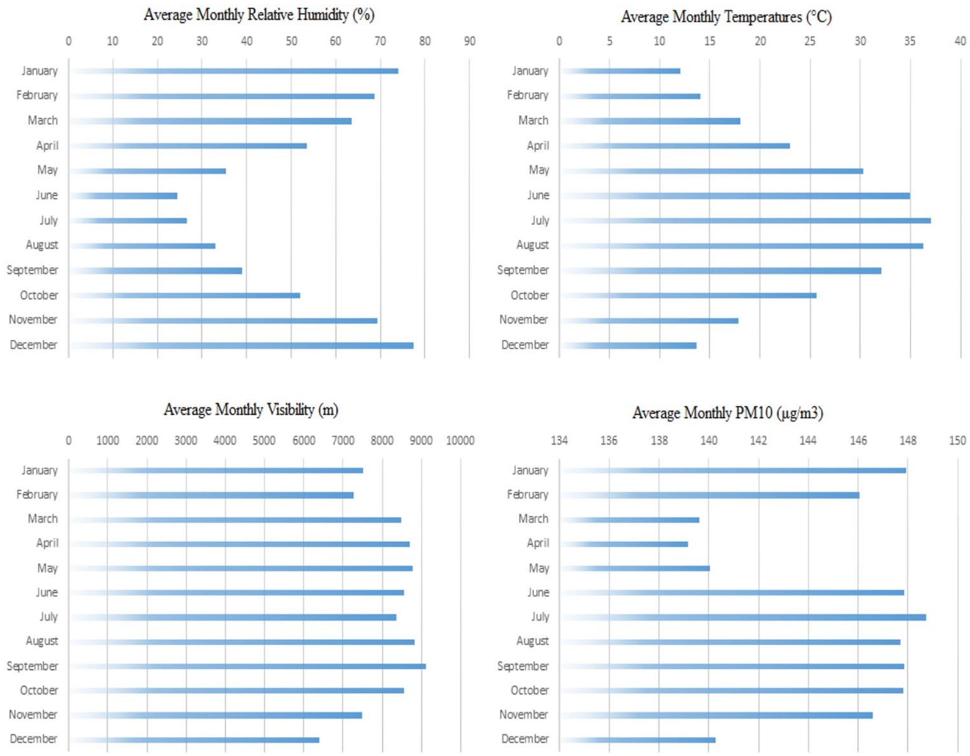


Figure 3. Average monthly relative humidity, temperature, visibility, and PM_{10} in Dezful during 2014 to 2019.

intensified effect of the MED in Dezful City (Tables 3 and 4). Table 3 shows the Excess Risk in Dezful for total non-accidental, cardiovascular, and respiratory deaths caused by dust storms. As shown in this table, although dust storms were not significantly related to total non-accidental and cardiovascular mortality, in the main effects, intensified effect, and serious intensified effect, the dust storms significantly increased the risk of respiratory mortality in lag_6 (main effects: 5.49 [0.91, 10.27], intensified effect: 11.13 [1.81, 21.31], serious intensified effect: 20.77 [3.27, 41.25]) (Table 3).

Additionally, Table 4 shows the Excess Risk in Dezful for non-accidental subgroups mortality caused by dust storms. As shown in this table, in terms of the main effects, intensified effect, and serious intensified effect, the dust storms were found to be significantly related to mortality in people aged <15 years old in lag_4 and lag_5 (lag_4 main effects: 34.17%, lag_4 intensified effect: 78.71%, lag_4 serious intensified effect: 182.31%, lag_5 main effects: 32.19%, lag_5 intensified effect: 73.54%, lag_5 serious intensified effect: 167.89%) and 15 to 64 years old in lag_6 (lag_6 main effects: 3.28%, lag_6 intensified effect: 6.59%, lag_6 serious intensified effect: 12.09%)) (Table 4).

Moreover, Table 5 shows the Cumulative excess risk in Dezful for non-accidental, respiratory, and cardiovascular mortality caused by dust storms. As indicated in this table, no significant cumulative excess risk mortality was found during the dust storms (Table 5).

Discussion

According to Hoffman, days with a PM_{10} concentration of more than 200 µg/m^3 and visibility of less than 2000 m are considered as dust storm days.[40] In recent years, increasing dust storms worldwide have caused many adverse effects on global health.[5-7,48] The origins of these dust storms are scattered all over the world, including the Saharan Desert, the Asian Deserts, the Pacific to the Central Western North America Desert, and the Australian Desert.[6] It is noteworthy that particles in dust storms can enter the respiratory tract through the airways and their chemical, physical, and biological properties can lead to human health disorders.[5,6,48] In addition, as the frequency, timing, and intensity of these storms increase, their health effects get worse.[5,7,48]

To the best of our knowledge, this study is the first study used DLNM and DLM with quasi-Poisson method to investigate the effect of MED on mortality in the Middle Eastern region. A significant adverse effect of MED on mortality was found in Dezful City. Notably, this study has a few strengths compared to the previous studies: (1) this study covered a longer-term period (5-years), while other studies in this region have focused on short-term episodes[12]; (2) in this study, actual and observed data were used; and (3) this study was conducted in a city with no industrial pollutants, and thus the increase in PM_{10} concentration is directly related to the natural dust and dust storms.

Our results showed statistically significant relationships between the MED and age-specific mortality (under 15 and 15-64 years of age) and respiratory mortality in Dezful City. However, no further significant relationships were found between the other lag days and cardiovascular

Table 2. Latitude, population, daily death, and meteorology information about Dezful city.

VARIABLE	VALUE
Latitude	48.39°32.38′
Population (people)	444 000
Daily death number mean (SD)	
Total death (NAD)	8.33 (3.07)
Respiratory death (RD)	0.636 (0.60)
Cardiovascular death (CVD)	3.53 (1.9)
Age (y) mean (SD)	
$<$15	1.17 (1.13)
15-64	2.88 (1.75)
65-75	1.14 (1.06)
⩾75	3.13 (1.83)
Gender (number) mean (SD)	
Male	4.87 (2.27)
Female	3.45 (1.93)
Daily mean temperature (°C) mean (SD)	
Daily temperature (mean [SD])	24.67°C (9.34°C)
Minimum temperature	17.12°C (7.84°C)
Maximum temperature	33.08°C (10.73°C)
Daily relative humidity (%) mean (SD)	
DRH (%) (mean [SD])	51.23% (21.25%)
Dust storms characteristic	
Dust storms day (number [%])	274 days (14.9%)
Daily mean PM_{10} during MED and non-MED (μg/m³)	431.1 and 101.5 μg/m³
PM_{10} (μg/m³)	
50 percentiles in non-MED days	112
50 percentiles in MED days	274
75 percentiles in-MED days	432
90 percentiles in MED days	684

Abbreviation: SD, standard deviation.

mortality. In addition to mutual reasons and inconsistency of findings of this study with other similar studies and cases mentioned below on insignificance of mortality risks (in terms of the effect of dust storms), according to findings of the current study, this could also be due to the use of early warning systems in the recent years in this area (since 2010).

In this study, no significant relationship was found between dust storms and cardiovascular mortality. Regarding the effects of MED storms on cardiovascular death, Al et al[8] and Al-Taiar et al[51] in 2 studies conducted in Turkey and Kuwait, respectively stated that the MED storms have no significant effect on increasing the risk of cardiovascular deaths. These results can be in line with the present study in Dezful City. However, the results of similar studies conducted in other parts of the world have shown that Saharan[52] and East Asian dust storms[53,54] were significantly associated with deaths resulting from heart diseases.

Although, some studies have reported that deaths due to dust storms did not increase significantly for all-cause,[20,51] respiratory,[51,53] cardiovascular,[51] and cerebrovascular mortality,[52] this difference in findings may be due to the differences found in the origin and the type of pollutants present in dust storms in East Asia and the Saharan in comparison with the Middle East.[51,55] Al-Taiar and Thalib[51] also stated that there is no significant relationship between MED storms and daily mortality in Kuwait, which is in line with the present study on insignificance of the effects of dust storms on total daily deaths in Dezful City. Also, Achilleos et al in a study in Kuwait did not express a significant relationship between dust storms and daily deaths in the Kuwaits. However, it has been further stated that daily non-accidental deaths resulting from deaths of the Kuwaitis and non-Kuwaitis together have increased considerably, and Achilleos et al[56] considered non-indigenous people as well, which influenced the results of the study significantly and therefore, the study cannot be considered as a coherent one. On the other hand, Shahsavani et al in a study conducted in Iran on the health effects of dust storms in the Middle East stated that increase in PM_{10} concentration following dust storms compared to non-dust storm days increased the risk of death in the lag_0, but in other $lags_{1, 2, 3, \text{and } 4}$, these deaths were not significant, and these results, except for the increased death in lag_0, can be somewhat in line with the present study. However, the study by Shahsavani et al[12] has only covered a 2-year period and has been conducted in Ahvaz City (Khuzestan Province, Iran), which is a large industrial city (because of oil production) with very high industrial pollutants. Notably, Perez et al[55] declared that Saharan coarse dust has increased the risk of death in Spain but coarse local dust did not increase the risk of death and argued that dust storms reaching new destinations from faraway places lose their larger particles and are combined with human and biological pollutants and hence, are more toxic than particles from local dust storms. Therefore, due to the fact that dust storms in Khuzestan Province are sometimes local and not far from their origin, these may be less toxic and cause less mortality.[33,51,55] In this regard, Borna stated that most dust storms in Khuzestan Province result from the 2 centers including western region of Baghdad and Mosul to Bahr al-Mulhab and Hoor-al-Azim Wetland in Khuzestan Province itself. The locality of storms originating from Hoor-al-Azim Wetland as well as short

Table 3. Excess non-accidental, respiratory, and cardiovascular risk mortality (%) and 95% CI for the association with Middle Eastern dust storms at lag_0 to lag_7 days in Dezful city during 2014 to 2019.

LAG	MORTALITY	MAIN EFFECT	INTENSIFIED EFFECT	SERIOUS INTENSIFIED EFFECT
	CONFIDENCE INTERVAL	ER (95% CI)	ER (95% CI)	ER (95% CI)
Lag_0	Non-accidental	0.82 (−1.08, 2.77)	1.64 (−2.12, 5.56)	2.96 (−3.77, 10.16)
	RD	0.77 (−5.18, 7.11)	1.54 (−9.97, 14.54)	2.77 (−17.13, 27.47)
	CVD	0.83 (−1.54, 3.26)	1.64 (−3.03, 6.55)	2.96 (−5.36, 12.02)
Lag_1	Non-accidental	−1.16 (−2.80, 0.50)	−2.29 (−5.47, 0.99)	−4.05 (−9.57, 1.79)
	RD	−2.17 (−8.52, 4.60)	−4.25 (−16.13, 9.30)	−7.48 (−26.98, 17.23)
	CVD	−0.22 (−2.13, 1.71)	−0.44 (−4.16, 3.42)	−0.79 (−7.32, 6.20)
Lag_2	Non-accidental	0.08 (−1.05, 1.23)	0.16 (−2.07, 2.46)	0.30 (−3.67, 4.44)
	RD	−1.70 (−6.29, 3.10)	−3.33 (−12.04, 6.23)	−5.88 (−20.50, 11.41)
	CVD	0.36 (−0.97, 1.71)	0.71 (−1.91, 3.42)	1.28 (−3.40, 6.20)
Lag_3	Non-accidental	0.30 (−0.82, 1.44)	0.59 (−1.62, 2.86)	1.06 (−2.89, 5.18)
	RD	−2.04 (−6.66, 2.80)	−4.00 (−12.74, 5.61)	−7.04 (−21.62, 10.26)
	CVD	0.76 (−0.54, 2.09)	1.52 (−1.07, 4.18)	2.73 (−1.92, 7.61)
Lag_4	Non-accidental	−0.44 (−1.58, 0.71)	−0.86 (−3.10, 1.42)	−1.54 (−5.48, 2.55)
	RD	−1.62 (−5.75, 2.68)	−3.19 (−11.05, 5.37)	−5.63 (−18.89, 9.80)
	CVD	0.31 (−1.04, 1.69)	0.62 (−2.05, 3.37)	1.11 (−3.64, 6.10)
Lag_5	Non-accidental	−0.46 (−1.61, 0.69)	−0.91 (−3.16, 1.38)	−1.63 (−5.58, 2.48)
	RD	1.72 (−2.18, 5.79)	3.44 (−4.27, 11.77)	6.23 (−7.50, 22.01)
	CVD	−0.71 (−2.09, 0.69)	−1.39 (−4.09, 1.37)	−2.48 (−7.20, 2.47)
Lag_6	Non-accidental	0.67 (−0.85, 2.23)	1.33 (−1.68, 4.45)	2.40 (−2.99, 8.10)
	RD	**5.49 (0.91, 10.27)***	**11.13 (1.81, 21.31)***	**20.77 (3.27, 41.25)***
	CVD	−1.29 (−3.27, 0.71)	−2.54 (−6.35, 1.41)	−4.51 (−11.07, 2.53)
Lag_7	Non-accidental	−0.60 (−2.31, 1.12)	−1.19 (−4.52, 2.24)	−2.13 (−7.93, 4.04)
	RD	−3.48 (−9.67, 3.13)	−6.76 (−18.21, 6.29)	−11.76 (−30.18, 11.52)
	CVD	0.05 (−1.98, 2.13)	0.10 (−3.88, 4.26)	0.19 (−6.83, 7.75)

Abbreviations: CVD, cardiovascular death; NAD, non-accidental death; RD, respiratory death.
Bold typeface with*: indicates statistical significance at $P < .05$.

distance of foreign sources (of storms) to Khuzestan Province can be considered among the reasons for the lack of significant increase in mortality in some lags.[33] In the present study, a significant relationship was observed between the dust storms and daily deaths in 3 $lags_{4,\,5,\text{ and }6}$ in the 2 age groups. This was significant in $lags_{4\text{ and }5}$ in children under 15 years old and in lag_6 in the people aged between 15 and 64 years old. In this regard, Achilleos et al[56] in Kuwait also found that deaths in the adult age group in Kuwait were significantly associated with dust storms, and that dust storms also increased the risk of child death, however, it was not significant. Also, Al-Taiar and Thalib[51] in a research done in Kuwait stated that the risk of daily death increased in children under 15 years old in Kuwait in most lags ($lags_{0,\,1,\,2,\text{ and }3}$) but this increase was not significant. More interestingly, there was no statistically significant relationship between dust storms and the risk of death in $lags_{0,\,1,\,3,\text{ and }5}$ for people over 65 years old. Other studies on the health effects of dust storms in the Middle East have not analyzed age in death cases.[8,12]

On the other hand, some similar studies conducted in other parts of the world have shown conflicting results. According to Zauli Sajani et al[57] there is a statistically significant relationship between dust storms and deaths in the people over 75 years of age in Italy. Chan and Ng,[53] Hwang et al,[58] and also stated that

Table 4. Excess non-accidental subgroups mortality (%) and 95% CI for the association with Middle Eastern dust storms at single lag_0 to lag_7 days in Dezful city during 2014 to 2019.

LAG	MORTALITY	MAIN EFFECT	INTENSIFIED EFFECT	SERIOUS INTENSIFIED EFFECT
	CONFIDENCE INTERVAL	ER (95% CI)	ER (95% CI)	ER (95% CI)
Lag_0	<15	12.64 (−9.90, 40.84)	26.52 (−18.62, 96.70)	52.26 (−30.80, 235.10)
	15-64	1.93 (−1.03, 4.98)	3.85 (−2.030, 10.09)	6.99 (−3.60, 18.75)
	65-74	1.94 (−3.34, 7.53)	3.88 (−6.50, 15.42)	7.04 (−11.32, 29.22)
	⩾75	1.11 (−1.82, 4.13)	2.20 (−3.56, 8.33)	3.98 (−6.28, 15.38)
	Male	0.29 (−2.18, 2.83)	0.58 (−4.26, 5.67)	1.04 (−7.49, 10.37)
	Female	0.29 (−1.44, 2.07)	2.78 (−3.00, 8.92)	5.03 (−5.31, 16.50)
Lag_1	<15	−19.54 (−49.11, 27.19)	−34.92 (−73.66, 60.82)	−53.60 (−90.79, 133.81)
	15-64	−1.79 (−4.52, 1.02)	−3.50 (−8.74, 2.03)	−6.18 (−15.09, 3.65)
	65-74	−0.52 (−5.14, 4.30)	−1.04 (−9.90, 8.69)	−1.85 (−17.01, 16.06)
	⩾75	−1.09 (−3.57, 1.43)	−2.16 (−6.93, 2.85)	−3.82 (−12.04, 5.16)
	Male	−0.70 (−2.78, 1.40)	−1.39 (−5.41, 2.80)	−2.47 (−9.47, 5.06)
	Female	−2.07 (−4.70, 0.62)	−4.05 (−9.07, 1.23)	−7.13 (−15.63, 2.22)
Lag_2	<15	−10.23 (−31.48, 17.58)	−19.21 (−52.61, 37.71)	−31.70 (−73.68, 77.19)
	15-64	1.17 (−0.65, 3.04)	2.33 (−1.29, 6.09)	4.21 (−2.30, 11.16)
	65-74	−0.29 (−3.55, 3.07)	−0.58 (−6.89, 6.16)	−1.03 (−11.99, 11.28)
	⩾75	−0.54 (−2.29, 1.23)	−1.07 (−4.48, 2.45)	−1.91 (−7.86, 4.42)
	Male	0.76 (−0.67, 2.22)	1.51 (−1.31, 4.43)	2.73 (−2.34, 8.07)
	Female	−0.82 (−2.63, 1.00)	−1.62 (−5.12, 2.00)	−2.89 (−8.98, 3.60)
Lag_3	<15	14.07 (−5.20, 37.27)	29.69 (−10.02, 86.96)	59.17 (−17.20, 206.03)
	15-64	0.93 (−0.89, 2.80)	1.86 (−1.76, 5.62)	3.35 (−3.12, 10.27)
	65-74	0.23 (2.96, 3.54)	0.46 (−5.78, 7.12)	0.83 (−10.09, 13.08)
	⩾75	0.05 (−1.66, 1.79)	0.10 (−3.25, 3.58)	0.18 (−5.74, 6.49)
	Male	0.29 (−1.14, 1.75)	0.57 (−2.25, 3.48)	1.03 (−3.99, 6.31)
	Female	0.32 (−1.43, 2.11)	0.64 (−2.81, 4.22)	1.14 (−4.98, 7.67)
Lag_4	<15	**34.17 (17.10, 53.71)***	**78.71 (36.60, 133.80)***	**182.31 (74.64, 356.36)***
	15-64	−1.26 (−3.21, 0.72)	−2.48 (−6.24, 1.43)	−4.39 (−10.88, 2.57)
	65-74	0.12 (−3.09, 3.46)	0.25 (−6.03, 6.95)	0.45 (−10.52, 12.77)
	⩾75	−0.15 (−1.89, 1.61)	−0.30 (−3.71, 3.22)	−0.54 (−6.53, 5.82)
	Male	−1.06 (−2.57, 0.46)	−2.09 (−5.03, 0.92)	−3.71 (−8.81, 1.66)
	Female	0.29 (−1.44, 2.07)	0.59 (−2.83, 4.14)	1.06 (−5.01, 7.52)
Lag_5	<15	**32.19 (15.20, 51.69)***	**73.54 (32.24, 127.74)***	**167.89 (64.81, 335.44)***
	15-64	−0.70 (−2.65, 1.28)	−1.38 (−5.17, 2.55)	−2.46 (−9.06, 4.61)
	65-74	−0.61 (−3.89, 2.78)	−1.20 (−7.54, 5.57)	−2.13 (−13.08, 10.18)

(Continued)

Table 4. (Continued)

LAG	MORTALITY	MAIN EFFECT	INTENSIFIED EFFECT	SERIOUS INTENSIFIED EFFECT
	CONFIDENCE INTERVAL	ER (95% CI)	ER (95% CI)	ER (95% CI)
	⩾75	−0.77 (−2.54, 1.02)	−1.53 (−4.97, 2.03)	−2.72 (−8.71, 3.66)
	Male	−0.72 (−2.24, 0.80)	−1.43 (−4.37, 1.59)	−2.54 (−7.68, 2.87)
	Female	−0.09 (−1.88, 1.73)	−0.18 (−3.68, 3.44)	−0.32 (−6.48, 6.24)
Lag_6	<15	9.92 (−12.84, 38.65)	20.55 (−23.78, 90.70)	39.68 (−38.46, 217.07)
	15-64	**3.28 (0.92, 5.70)***	**6.59 (1.83, 11.57)***	**12.09 (3.30, 21.63)***
	65-74	−1.58 (−6.26, 3.33)	−3.10 (−12.00, 6.69)	−5.48 (−20.43, 12.27)
	⩾75	−0.84 (−3.26, 1.62)	−1.66 (−6.33, 3.24)	−2.95 (−11.04, 5.86)
	Male	1.53 (−0.39, 3.49)	3.05 (−0.77, 7.02)	5.52 (−1.38, 12.90)
	Female	−0.07 (−2.49, 2.39)	−0.15 (−4.85, 4.78)	−0.27 (−8.51, 8.72)
Lag_7	<15	−13.49 (−48.98, 46.65)	−24.90 (−73.53, 113.06)	−40.07 (−90.70, 286.56)
	15-64	−0.62 (−3.40, 2.23)	−1.23 (−6.61, 4.45)	−2.19 (−11.51, 8.10)
	65-74	−2.55 (−7.86, 3.05)	−4.99 (−14.94, 6.12)	−8.74 (−25.12, 11.21)
	⩾75	0.56 (−1.92, 3.11)	1.11 (−3.76, 6.24)	2.00 (−6.62, 11.43)
	Male	−0.43 (−2.59, 1.77)	−0.85 (−5.06, 3.54)	−1.52 (−8.87, 6.42)
	Female	−0.83 (−3.49, 1.90)	−1.63 (−6.78, 3.80)	−2.90 (−11.80, 6.90)

Bold typeface with*: indicates statistical significance at $P < .05$.

the risk of death due to dust storms is significantly higher for people over 65 years of age. However, some other similar studies either have not analyzed deaths by age group or have analyzed them separately from other ages.[12] Also, in Iran, early warning systems for dust storms generally prohibit the elderly and sick people from going outside on dusty days, which might have influenced the results of this study. However, according to the results of the studies conducted by Achilleos et al[56] and Al-Taiar[59] in Kuwait, it is recommended to conduct more detailed studies in Dezful City and other cities exposed to dust storms in the Middle East.

Finally, a significant relationship was found between dust storms and respiratory deaths in lag_6, which is in line with other studies conducted in the Middle East and other countries.[16] This is a serious warning and is considered as an issue that should be addressed. More detailed studies on respiratory mortality in cities affected by dust storms in the Middle East should be conducted to investigate this problem in more details. In this regard, Khaniabadi et al[16] stated that dust storms have increased the risk of respiratory mortality in Ilam Province in Iran by 7.3% (CI 4.9%-19.5%). Gravandi et al[31] and Khaniabadi et al[27] in studies conducted in Ahvaz and Khorramabad Cities (Iran) also stated that the increase in concentration of fine particles from dust storms in the Middle East significantly leads to hospitalization of patients with respiratory diseases, confirming that the MED may have more effects on the increase in respiratory problems. Also, elsewhere in the world, Zauli Sajani et al[57] and Jimenez et al[60] in studies conducted in Italy and Spain stated that Saharan dust storms in some European cities increase the risk of respiratory death. However, Al-Taiar[59] in a study done in Kuwait did not show a significant relationship between respiratory death and dust storms. Still, it should be noted that Al-Taiar performed its respiratory analysis up to lag_5 and the relationship between mortality and dust storms was significant in lag_6 in the present study.

Limitations

In this study, we selected the data from May 2014 because PM_{10} measurement in Dezful began from May 2014. We could not analyze the size-specific effects of particulate matter and the chemical composition of dust storms. Another limitation of this study is the biases inherent in ecological studies, including aggregated data and the fact that the results at the aggregated level cannot be generalized directly to the individual level (Ecological Fallacy). The retrospective nature of this study may also be a limiting factor. The current study may be short of having the ability to track the impact of dust events on daily mortality due to the

Table 5. Cumulative excess non-accidental, respiratory, and cardiovascular risk mortality (%) and 95% CI for the association with MED dust storms at lag_{0-2} and lag_{0-7} days in Dezful city during study period.

LAG	MORTALITY	MAIN EFFECT	INTENSIFIED EFFECT	SERIOUS INTENSIFIED EFFECT
	CONFIDENCE INTERVAL	CER (95% CI)	CER (95% CI)	CER (95% CI)
Lag_{0-2}	Non-accidental	−0.25 (−4.94, 4.52)	−0.47 (−9.67, 9.02)	−0.79 (−17.01, 16.39)
	<15	−17.13 (−90.49, 85.62)	−27.61 (−144.89, 195.24)	−33.04 (−195.28, 446.11)
	15-64	1.31 (−6.21, 9.05)	2.68 (−12.07, 18.22)	5.02 (−20.99, 33.58)
	65-74	1.12 (−12.04, 14.91)	2.25 (−23.30, 30.27)	4.15 (−40.33, 56.57)
	⩾75	−0.53 (−7.68, 6.80)	−1.02 (−14.98, 13.64)	−1.75 (−26.20, 24.97)
	Male	0.35 (−5.63, 6.46)	0.70 (−11.00, 12.91)	1.29 (−19.31, 23.50)
	Female	−1.50 (−8.86, 6.05)	−2.89 (−17.21, 12.16)	−4.99 (−29.93, 22.34)
	RD	−3.10 (−19.99, 14.83)	−6.05 (−38.16, 30.08)	−10.59 (−64.62, 56.12)
	CVD	0.96 (−4.65, 6.70)	1.92 (−9.12, 13.40)	3.45 (−16.09, 24.43)
Lag_{0-7}	Non-accidental	−0.78 (−12.14, 10.73)	−1.52 (−23.77, 21.39)	−2.63 (−41.90, 38.76)
	<15	59.72 (−125.22, 313.62)	149.99 (−183.39, 747.53)	375.95 (−202.20, 1847.59)
	15-64	2.94 (−15.45, 21.80)	6.04 (−30.03, 43.87)	11.42 (−52.27, 80.78)
	65-74	−3.26 (−36.14, 31.0)	−6.32 (−69.61, 62.75)	−10.93 (−119.59, 116.10)
	⩾75	−1.69 (−18.97, 15.98)	−3.30 (−37.02, 31.96)	−5.78 (−64.87, 58.26)
	Male	−0.05 (−14.59, 14.76)	−0.04 (−28.50, 29.50)	0.06 (−50.06, 53.69)
	Female	−1.87 (−19.61, 16.28)	−3.63 (−38.19, 32.57)	−6.27 (−66.74, 59.41)
	RD	−3.04 (−43.37, 39.53)	−5.42 (−82.62, 80.45)	−8.01 (−139.57, 150.98)
	CVD	0.09 (−13.60, 14.04)	0.22 (−26.59, 28.02)	0.50 (−46.77, 50.91)

Abbreviations: CVD, cardiovascular death; NAD, non-accidental death; RD, respiratory death.
Bold typeface: indicates statistical significance at $P < .05$.

insignificant numbers of respiratory deaths Also, we could not determine the local and non-local origin of dust storms, which according to the results of Perez et al[55] could have been a significant help in summarizing the results of this study.

Conclusion

In this study, significant and thought-provoking results were obtained regarding the effect of the MED storms on daily deaths in people under 65 years of age and respiratory deaths in Dezful City. In addition to having almost similar findings to the previous studies conducted in this region, findings of this study emphasized that all age groups and patients with chronic diseases need to take extra precautions during occurrence of dust storms. Therefore, these results should encourage responsible institutions to implement public health policies in order to reduce health risks of this phenomenon. Also, because of the global warming, industrialization, and increase in droughts from one hand, and slow speed of programs to reduce desertification and eliminate dust sources,[20,24] for communities exposed to dust storms, it is suggested to stop dust storms cycles through cultivation of new climate-compatible plant species in desert areas in addition to evaluating the health effects of this phenomenon in their region. Also, early warning systems can continue to function in order to announce any incoming storms and protect the society from being affected. Not only the elderly or sick people should be prevented from moving around as the dust starts to sweep across the area, but also healthy people and younger age groups in particular should also be prevented from going out and doing work during the dust storms.

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Author Contributions

HA, AOT, and RSH designed the study; HA collected the data; HA, RSH, and MSY analyzed and interpreted the data. HA, AOT, A Ardalan, RSH, CS, and A Asgary prepared the manuscript. All authors contributed to the drafting and final review of the manuscript. The author (s) read and approved the final manuscript.

Ethics Approval and Consent to Participate

Current study was approved by the Ethics Committee of Tehran University of Medical Sciences (TUMS) Ethics Code: IR.TUMS.SPH.REC.1399.004, and also all methods were performed in accordance with the relevant guidelines and regulations. This study does not require informed consent directly from the patient since only unnamed archived data has been used. Therefore, the consent has been waived by the ethics committee. However, written permission was obtained from the competent authorities to use this data.

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Availability of Data and Materials

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

Supplemental Material

Supplemental material for this article is available online.

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