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Impacts of Middle Eastern-Dust storms on human health

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Abstract

Air pollution is emerging as a significant risk factor for human health in developing countries, particularly in Iran where air pollutant concentrations are elevated. Currently, knowledge of health effects of air pollution in developing countries is limited. The objective of this study was to estimate the excess number of hospitalizations for Chronic Obstructive Pulmonary Disease (COPD) and the number of excess cases of Respiratory Mortality (RM) associated with daily averages levels of particulate matter less than 10 µm in diameter (PM_{10}) in Ilam (Iran) over 1-year period (2015-2016). The excess instances of COPD and RM were estimated based on relative risk (RR) and baseline incidence (BI). The numbers of excess cases for COPD and RM during normal, dusty and Middle Eastern Dust (MED) storm days were 60 and 5, 200 and 15, and 78 and 6 persons, respectively. The results also showed that about 4.9% (95% CI: 3.0-6.8%) of hospital visits for COPD and 7.3% (CI: 4.9-19.5%) of RM could be attributed to PM_{10} concentrations per 10 µg/m^3 increase, respectively. It was found that a higher number of people were admitted to hospital when PM_{10} concentrations exceed

200 μg/m^3 related to the MED events. Significant exposure to air pollutants, particularly during MED event, led to an excess of hospital admissions for COPD and an excess of the respiratory mortality. Several immediate actions such as strategic management of water bodies or planting of tree species in urban areas could be effective to mitigate the impact of desert dust on respiratory illness.

Keywords: PM_{10}; Chronic Obstructive Pulmonary Disease; Respiratory Mortality; Hospital Admissions; Ilam

1. Introduction

Many studies have shown that airborne particulate matter (PM) is a harmful airborne pollutant adversely affecting cardiovascular health and has respiratory health effects (e.g. USEPA 2009a; Crooks et al. 2016). PM pollution is ubiquitous with direct emissions and also generated as secondary aerosol from biogenic and anthropogenic precursors (Sarigiannis et al. 2015). Airborne particles were characterized by measuring the PM with aerodynamic diameter less than 10 micrometer (PM_{10}) because below this size, particles can penetrate into the lung where they may have elicit harmful effects and strongly contributing to the health effects observed in urban environments (WHO 2006; Sicard et al. 2010; 2011; Martinelli et al. 2013; Zhou et al. 2014a).

Incidences of dust storms have increased in recent years and there is evidence that these dusts can move across long distances (Crooks et al. 2016). Indeed, in the last decades, southern, western, and southwestern Iran was frequently affected by Middle Eastern Dust (MED) storms, increasing the number of dusty days as well as the daily PM_{10} mean concentrations (Goudie 2014; Nourmoradi et al. 2016). These dust storms provide long-range transport of crustal particles (Kellogg and Griffin 2006) but also were reported to carry several pathogenic microorganisms (including *Mycobacterium, Brucella, Coxiella Burnetii, Clostridium perfingens, and Bacillus),* toxins and influenza viruses (Griffin 2007; Leski et al. 2011; Goudie 2014). Furthermore, metallic elements are bound to inhalable dust particles, and they could potentially affect respiratory function (Hong et al. 2010).

Kanatani et al. (2010) found that in Japan, Asian Dust Storms (ADS) worsen diseases such as asthma exacerbation in children and caused increased morbidity. Chien et al. (2012) found that there was a significant association between dust events and clinical hospitalizations due to respiratory diseases in children in Taiwan (Chien et al. 2012). Yang (2013) found that asthma, pneumonia, and tracheitis are caused by ADS in East Asia (Yang 2013). Epidemiological studies showed that high levels of airborne particles cause cardiovascular diseases such as myocardial infarction, stroke, heart failure, and venous thromboembolism (Martinelli et al. 2013; Crooks et al. 2016). Yang et al. (2005) and Kang et al. (2013) found that ADS were associated with an acute increase in hospital visits in Taiwan (Kang et al. 2013; Yang et al. 2005). In Cyprus, Middleton et al. (2008) found that cardiovascular visits increased after dust episodes (Middleton et al. 2008). Neophytou et al. (2013) reported that there was a 2.4% increase in daily cardiovascular mortality associated with a 10 $\mu g/m^3$ increase in PM_{10} levels during African Dust days (Neophytou et al. 2013).

Surprisingly, no human health effects caused by MED were reported until now in Iran. The main objective was therefore to assess, through an ecological study, the impact of MED on the excess number of hospital admissions due to Chronic Obstructive Pulmonary Disease and on the excess of the Respiratory Mortality over the 1-year period (2015-2016) in the Iranian city of Ilam, which is frequently exposed to desert dust.

2. Material and Methods

2.1. Study area

Ilam is a non-industrialized city with a population of 172,213 inhabitants in the center of Ilam Province, located in western Iran (Figure 1). Ilam has a cold semi-arid climate with an elevation of 1387 m above the sea level. The mean annual precipitation is 619.5 mm with minimum and maximum temperatures of -13.6˚C and 41.2˚C, respectively. The Zagros Mountains enclose the city on three sides. The MED storms come from the desert areas of western Asia particularly Iraq and Saudi Arabia. During some storm days, the visibility can be reduced to 200 m.

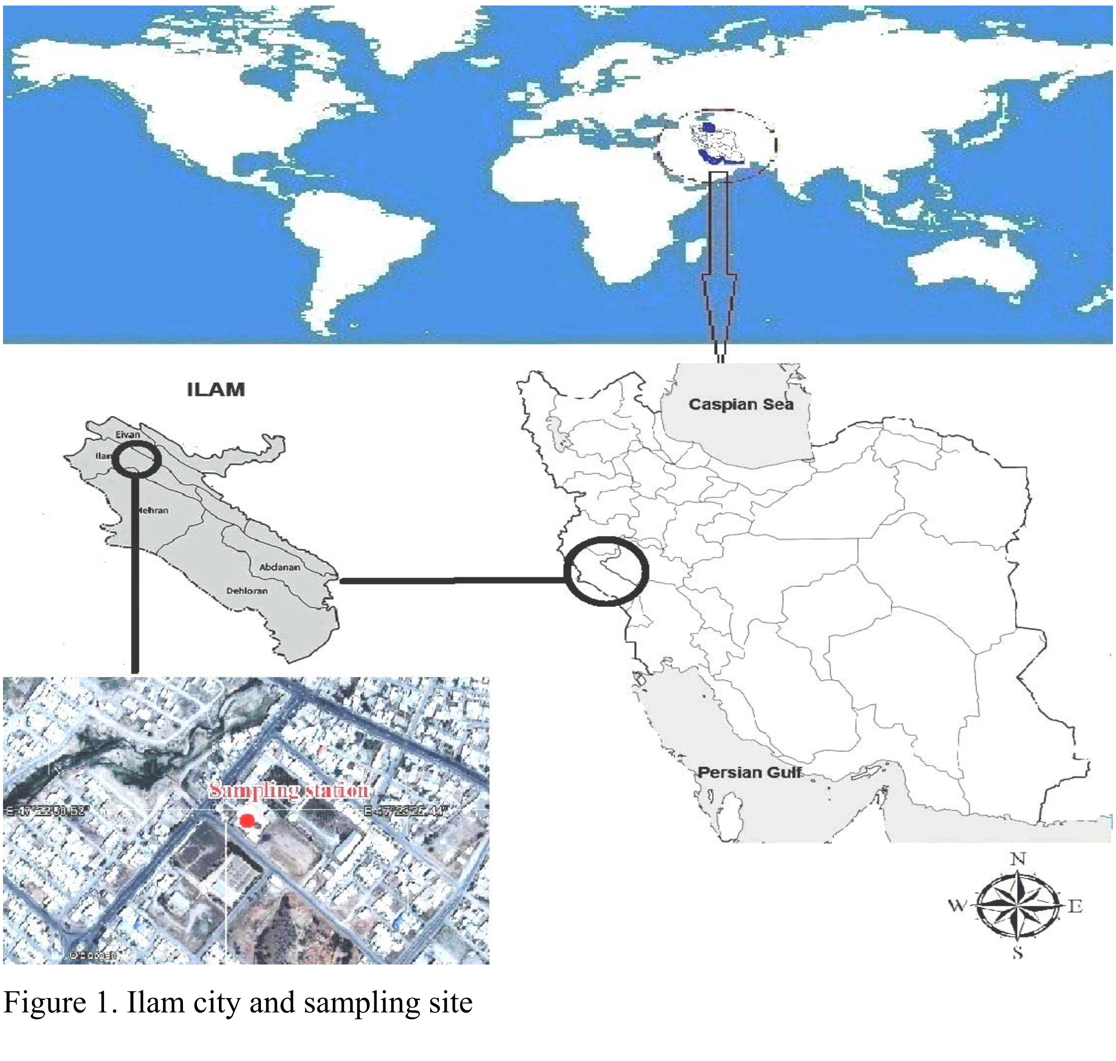

Figure 1. Ilam city and sampling site

2.2. Particulate matter sampling

To measure particulate matter, one air pollution-monitoring site (33°36′N, 47°22'E) has been established; its maintenance and operation is realized by the Ilam Environmental Protection Agency (IEPA). The hourly PM_{10} levels were determined for one-year daily monitoring using the beta attenuation method. Hourly PM_{10} concentrations from January 2015 to January 2016 were obtained from IEPA. The daily 24-hour averages were calculated from more than 75% of validated hourly data.

2.3. Air Quality Health Impact Assessment

In this study, AirQ2.2.3 software, developed by the World Health Organization (WHO), was used to assess hospitalizations for Chronic Obstructive Pulmonary Disease (COPD) and the Respiratory Mortality (RM). Following the International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10), J00-J99 is associated to diseases of the respiratory system, RM corresponds to ICD-10 codes J100-J118, J120-J189, J209-J499, and J690-J700 and J44 code is associated to COPD.

AirQ is a tool enabling the assessment of the health effects of exposure to a common air pollutant in a defined region over a given time period (Fattore et al. 2011; Omidi et al. 2016). The attributable proportion (AP) is defined as the fraction of health consequences in a population exposed to a specific air pollutant (Khaniabadi et al. 2016a). The AP can be calculated as:

$$AP = \sum\left(\left[RR(c)-1\right]*P(c)\right]\right)/\sum\left[RR(c)*P(c)\right] \tag{1}$$

where AP is the attributable proportion of the health impact, RR is the relative risk for a certain health impact in category "c" of exposure taken from prior epidemiological studies, and P(c) is the population proportion in category "c" of exposure.

Relative risk (RR) is the attributable health risk associated with people who have defined exposures and can be calculated by means of Eq. (2):

$$RR = \frac{\text{Probability of a health effect when exposed to air pollution}}{\text{Probability of a health effect when not exposed}} \tag{2}$$

The number of each case per population unit can be estimated as follows when the baseline frequency of the specific health impact in the population is known (Nourmoradi et al. 2015).

$$IE = I * AP \tag{3}$$

where IE is the number of cases attributable to air pollution per population unit and I is the population unit. Knowing the population size, the number of excess cases associated with the exposure can be calculated using Eq. (4):

$$NE = IE * N \tag{4}$$

where N and NE are the size of population under study and the number of excess cases, respectively.

In our study, 24-h PM_{10} mean concentrations, COPD and RM adverse health outcomes, and estimated exposed population data were the inputs to AirQ2.2.3 for the time period 2015- 2016.

2.4. Relative risk and baseline incidence

In epidemiological studies, particularly using the AirQ model, the main health-related parameters are relative risk (RR) and baseline incidence (BI). The RR is the possibility of developing illness (daily mortality and morbidity) due to the exposure to an air pollutant per μg/m^3 increase (Sicard et al. 2011; Khaniabadi et al. 2016a, b). For this study we used the published exposure-response relative risk functions and a particular set of RR values for a given health endpoint associated with increasing air pollution main pollutants. These functions and values have been published by the WHO (2001, 2004, 2008) and APHEA-2 (e.g. Sicard et al. 2011) under a procedure for health impact assessment for the study area. The APHEA-2 (Air Pollution and Health – a European Approach) project started as an attempt to provide quantitative estimates of the short term health effects of air pollution, using an extensive database from 26 European cities, with a combined population of over 30 million (15 cities with > 25 million people), through time series data and meta-analysis. The Table 1 presents the RR values published by the WHO (2001, 2004 and 2008) and APHEA-2 studies. The number of excess cases of COPD and RM, in exposed population, was estimated by RR and BI as proposed by the WHO (2006). The values of RR and BI (per 100,000 individuals) attributed to different mortality and morbidity causes are illustrated in Table 1. The RR and the BI values were taken from data files of the

AirQ software based on various peer-reviewed studies (Atkinson and Anderson 1997; Burret and Doles 1997; Touloumi 1997).

Table 1. Relative risk (RR) with confidence intervals (95% CI) and baseline incidence per 100,000 inhabitants used for evaluation of health effects.

Short-term effects	BI*	RR ** (95% CI***) per 10 μg/m^3 increase
Morbidity for chronic obstructive pulmonary diseases	1250	1.0080 (1.0048-1.0112) (Goudarzi et al. 2015a)
Respiratory mortality	48.4	1.013 (1.005-1.021) (Fattore et al. 2011)

*BI: Baseline Incidence, **RR: Relative Risk, ***CI: Confidence Interval

The PM_{10} data were pre-processed in Excel software to convert the data into input format of AirQ. The data needed for AirQ included average values, daily and annual, winter and summer days, winter, summer and annual mean values, winter and summer and annual maxima values as well as annual 98 percentile, the number of days when levels of the PM_{10} were in given intervals, and the population given in thousands. The results were compared with the United States National Ambient Air Quality Standards (NAAQS). Based on known health effects, an annual average concentration of 20 μg/m^3 was chosen as the long-term (annual mean) guideline value for PM_{10} (WHO, 2006) while 150 μg/m^3 was accepted as National Ambient Air Quality Standard according to the NAAQS (USEPA 2013).

2.5. Trajectories

Air parcel back trajectories were calculated using the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) 4.0 Model developed by NOAA/ARL (Stein et al. 2015; Rolph 2016) with meteorological data from the REANALYSIS data set.

3. Results

3.1. PM_{10} concentrations

Table 2 shows the number of days within each concentration interval. The highest number of days was in the interval level of 40-49 μg/m^3 (Table 2). The number of days with PM_{10} levels exceeding the NAAQS criteria was 180 days. The annual average, summer and winter averages, seasonal maxima values, and 98th percentile for PM_{10} concentrations were calculated with the AirQ2.2.3 software. The annual PM_{10} mean concentration in Ilam is about 78 μg/m^3. The PM_{10} average in summer was higher than the winter one, with average values of 87 and 69 μg/m^3, respectively. The annual maximum PM_{10} was observed in summer compared to the winter maximum, 769 μg/m^3 and 632 μg/m^3, respectively and the 98th percentile was 273 μg/m^3.

Table 2. Number of days in each PM_{10} interval

PM_{10} (μg/m^3)	**N**	**PM_{10} (μg/m^3)**	**n**	**PM_{10} (μg/m^3)**	**n**
<10	0	90-99	8	180-189	8
10-19	28	100-109	8	190-199	8
20-29	41	110-119	9	200-249	7
30-39	53	120-129	7	250-299	5
40-49	61	130-139	6	300-349	2
50-59	32	140-149	3	350-399	0
60-69	29	150-159	2	>=400	4
70-79	26	160-169	5	>=50	180
80-89	9	170-179	2	>=150	43

According to the Hoffmann classification for dust storms (DS), the number of days for the categories of normal, dusty, light dust storm, dust storm, strong dust storm, and seriously strong dust storm in Ilam are given in Table 3. According to dust events categories (Hoffmann et al. 2008), the sum of days related to DS1 and DS2 was 18 days. The number of days for dusty category (PM_{10}>=50 μg/m^3) was 182 days, i.e. slightly higher than the days in normal circumstances (PM_{10}< 50 μg/m^3), equivalent to 183 days.

Table 3. Classifications of normal days and dusty days and their occurrences

Category	Classification			Number of days
	Visibility (m)	Wind speed (m/s)	PM_{10} (μg/m^3)	
Normal days	-	-	< 50	183
Dusty days	>2000	-	50-200	164
Light dust storm (DS1)	<2000	-	200-500	16
Dust storm (DS2)	<1000	>17	500-2000	2
Strong dust storm (DS3)	<200	>20	2000-5000	0
Serious strong dust storm (DS4)	<50	>25	> 5000	0

3.3. Adverse health impacts

The association between Attributable Proportion (AP) and the cumulative number of excess cases of exposure to atmospheric PM_{10} among the population of Ilam is shown in Table 4. To assess the results of the present study, the lower, upper, and central values for RR have been considered. The numbers of excess cases (with 95% CI) for COPD during normal, dusty, and MED days for the central RR value were 60, 200, and 78 people, respectively. The estimated numbers of excess cases for RM were 4.6, 15.3, and 6.0 people during normal days, dusty days, and MED storm, respectively. Based on the central RR, the cumulative numbers of excess cases for clinical visits due to COPD and for RM were 338 and 26 persons, respectively, with AP percentages of 4.9% and 7.3% per 100,000 peoples. The ratios of number of excess cases in dusty air to normal air were 4.6 for both COPD and RM.

Table 4. Estimated attributable proportion (AP) percentage and number of excess cases (with 95% CI) in a year

Disease	AP (%)	Cases in Normal (<50 μg/m³)	Cases in Dusty (50-200 μg/m³)	Due to MED (>200 μg/m³)	Subtotal	D/N
COPD	4.9 (3.0-6.8)	60 (37-82)	200 (122-275)	78 (48-107)	338 (207-464)	4.6
RM	7.3 (4.9-19.4)	4.6 (3-12)	15 (11-41)	6 (4-11)	26 (18-70)	4.6

3.4. COPD and RM

Figure 2 shows the results of COPD and the RM quantification due to the exposure to airborne PM_{10} in Ilam obtained from the AirQ model. The diagrams show the cumulative number of each health outcome including the lower (lower curve), central (middle curve), and higher (upper curve) relative risks, corresponding to 5% (underestimated risk), 50% (central risk) and 95% (overestimated risk) confidence interval, respectively. Figure 2 also displays the cumulative number of excess cases relative to the PM_{10} concentration interval (µg/m³). Based on the central RR, the cumulative number of hospital admissions for COPD (RR=1.008) and the number of RM (RR=1.012) were 338 and 26 persons, respectively.

The results also showed that about 4.9% of hospital visits for COPD (95% CI: 3.0-6.8%) and 7.3% of the RM (CI: 4.9-19.5%) can be attributed to PM_{10} concentrations over 10 µg/m³, respectively. For each 10 µg/m³ increase in PM_{10} levels, the risk of admissions for COPD and the RM increased by 0.8 and 1.2%, respectively. In addition, 11.9% of health impacts due to PM_{10} exposure occurred at concentrations higher than 150 µg/m³, and 3.0% of estimated excess cases occurred during days with PM_{10} levels exceeding 200 µg/m³.

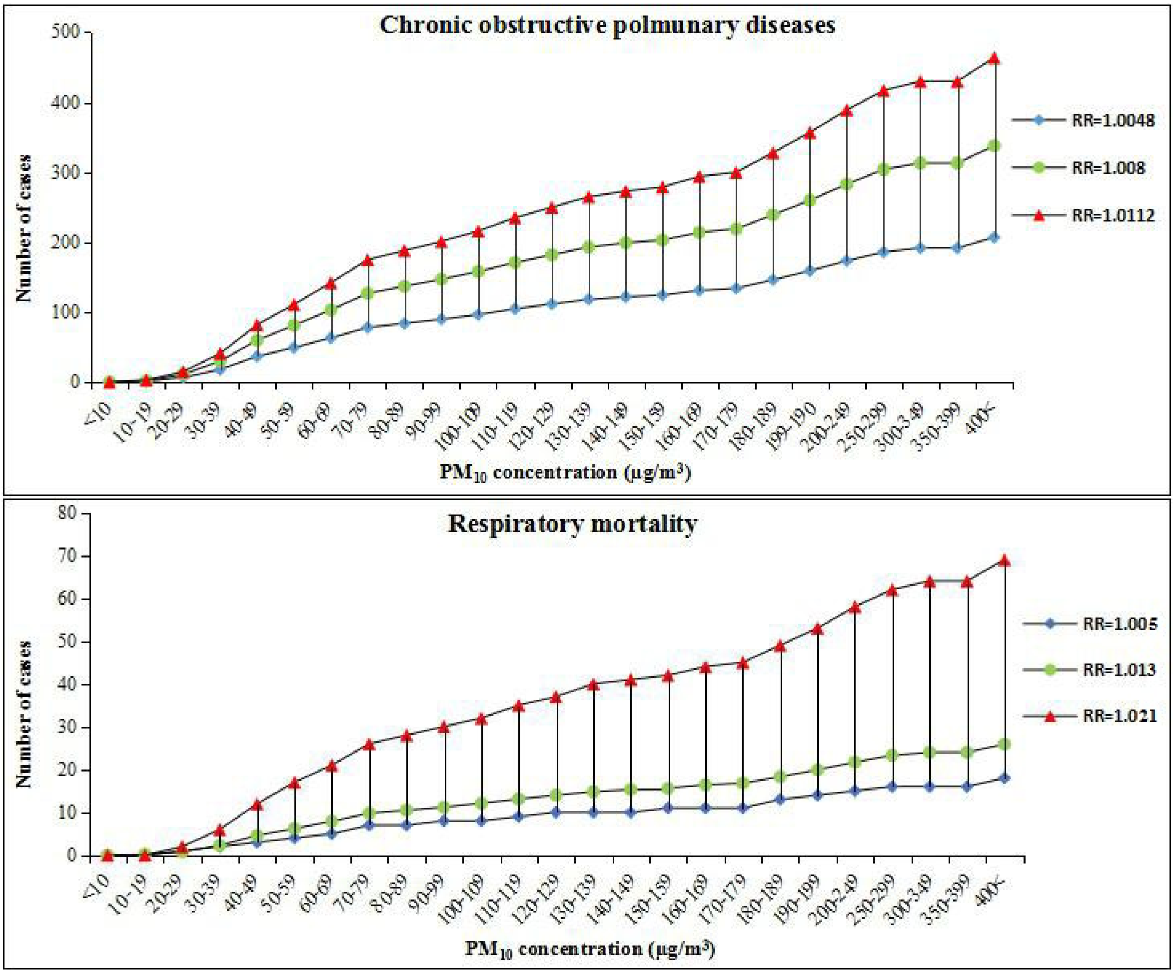

Figure 2. Number of hospital admissions for chronic obstructive pulmonary disease and respiratory mortality.

4. Discussion

In this study, the WHO health effects model AirQ was used to assess the health effects of particulate matter (PM_{10}) on the population of Ilam in western Iran. The impacts of PM_{10} were estimated by the increase in hospital admissions for COPD and by the RM for short-term exposures. AirQ2.2.3 has been used in prior epidemiological studies to assess the short-term health impacts of PM_{10} on mortality and morbidity cases (Tominz et al. 2005; Boldo et al. 2006; Shakour et al. 2011; Goudarzi et al. 2015a,b; Nourmoradi et al. 2016). The BI and RR were used to assess the impact of PM_{10} on the population of Ilam as inputs of AirQ model (Table 1). The BI value was compared with the World Bank Database (Bank 2012) to assess its accuracy. Our study showed that over the 1-year study period (2015-2016), the PM_{10} levels exceeded the NAAQS criteria during 180 days in Ilam; while in Kermanshah (Iran), the number of days with concentrations higher than 150 µg/m^3 in 2011 and 2012 were 138 and 63, respectively (Marzouni et al. 2016). The high hospital admissions in Ilam can be attributed to high exposures to Middle Eastern Dust (MED) storms coming from arid areas such as Iraq and Saudi Arabia (Shahsavani et al. 2012). MED storms are the main cause of dust events in the west of Iran, however, other pollution sources, including road traffic and industries, contribute to the recorded high PM_{10} levels (Marzouni et al. 2016).

In other investigations dealing with the differences between the MED and the normal conditions, daily PM_{10} concentrations above 200 $\mu g/m^3$ were considered (Al-Taiar and Thalib 2014; Marzouni et al. 2016). Base on this criterion, MED events occurred on 16 days from 2015 to 2016. The trajectories for the 10 highest 24-hour PM_{10} concentrations are presented in Figure 3. The high dust events arise from a variety of locations given that Ilam is located within a dry region surrounded by desert areas. By comparison, the number of recorded MED days in the study of Marzouni et al. (2016) was 17 days during 2012. The annual average of PM_{10} concentration was 116 $\mu g/m^3$ in Kermanshah (Iran) in 2012. The annual average and maximum PM_{10} value in Tabriz (Iran) were 110 and 157 $\mu g/m^3$ (Gholampour et al. 2014). The comparable values in Ilam were 78 and 769 $\mu g/m^3$, respectively. In comparison, the highest PM_{10} concentration in Ahvaz (Iran) was 728 $\mu g/m^3$ (Goudarzi et al. 2015a). The summer average of PM_{10} was higher than that of winter, which can be associated with highest temperatures and wind speeds leading to increased atmospheric turbulence and resuspension of dust from the blowing sand particles of the Middle Eastern areas (Habeebullah 2013).

The maximum person-days of exposure was determined in the PM_{10} range of 200-249 $\mu g/m^3$ in Makkah, Saudi Arabia (Habeebullah 2013). In Mazzano and Rezzato, Italy, the maximum percentage of the days on which people were exposed to high PM_{10} was in the interval of 40-49 $\mu g/m^3$ (Fattore et al. 2011), similar to the present study. The maximum person-days in Ilam were also on days with concentrations in the range of 40 to 49 $\mu g/m^3$.

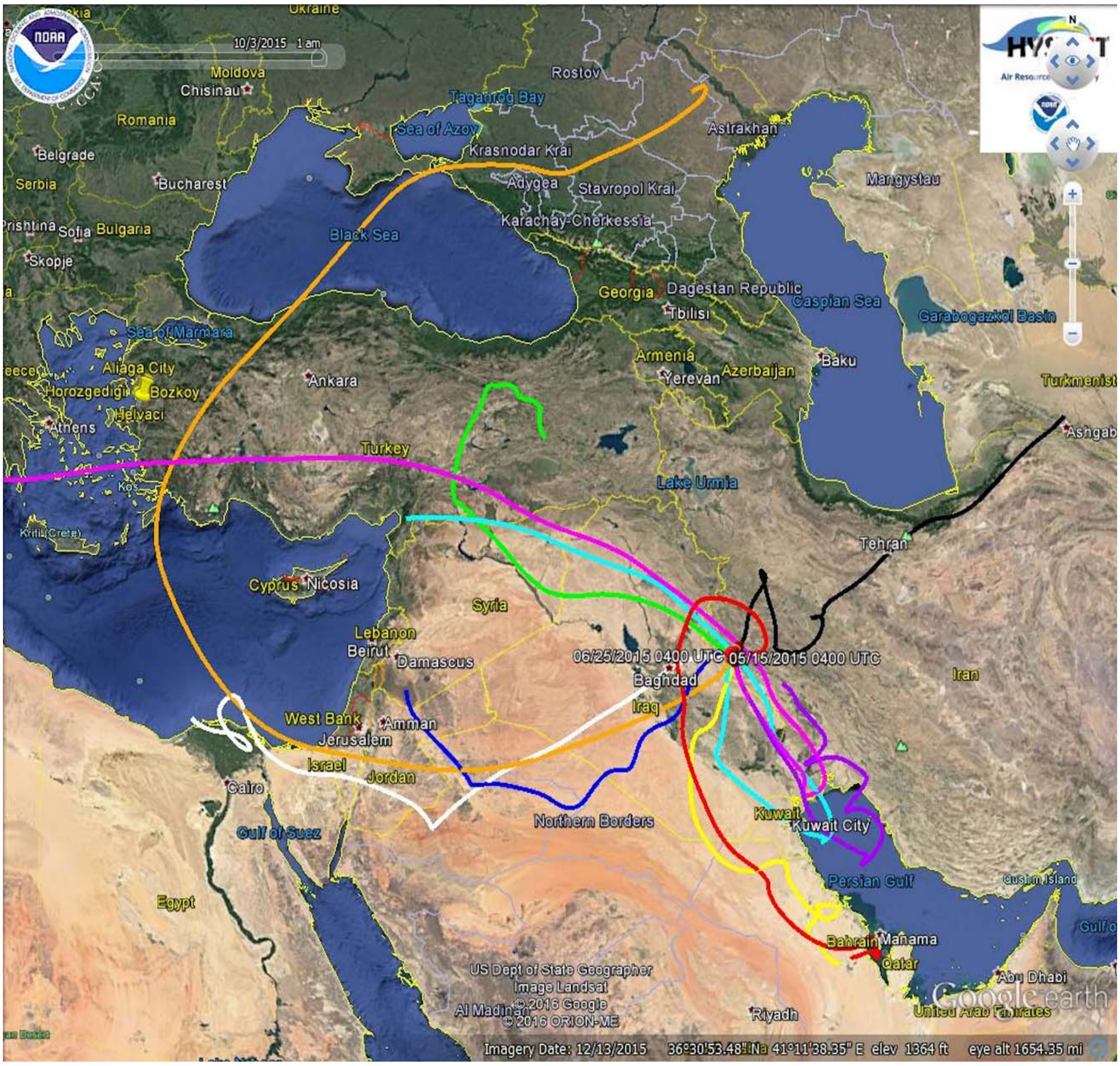

Figure 3. Map of the study region showing the back trajectories for 10 highest 24-hour MED storms, when PM_{10} concentrations were the highest, in 2015.

Indicators of “Attributable Proportion” (AP) and Relative Risk” (RR) are defined by the WHO. For a population of 172,000 people and based on a Baseline Incidence (BI) of 1250 and 48 for COPD and RM, annually, about 338 and 26 cases can be considered as excess in Ilam, respectively. In the United States, about 730,000 hospitalizations for COPD were recorded in 2007 (Torio and Andrews 2013). Also, in Ahvaz (Iran) almost 1602 persons were admitted to hospitals for COPD illness in 2012 (Goudarzi et al. 2015a). A significant association between PM_{10} concentrations and hospital visits with a central relative risk of 1.14 (1.01-1.29) was previously reported (Chen et al. 2010b; Guo et al. 2010). A study was conducted to determine the influence of Asian Dust Storm (ADS) on the hospital visits due to asthma and COPD. PM_{10} concentrations during ADS were found to increase to 147 $\mu g/m^3$;

whereas on normal days they averaged 62 μg/m^3. Hospital admissions for asthma and COPD (RR=1.21; 95% CI: 1.01-1.19 and RR=1.29; 95% CI: 1.05-1.59) respectively significantly increased during the days with ADS (Park et al. 2015). Goudarzi and Naddafi (2009) estimated that approximately 3.6% of COPD cases were associated with PM_{10} levels higher than 30 μg/m^3 (Goudarzi and Naddafi 2009). In Vancouver (Canada), a statistical association between particulate matter and COPD was observed (Brauer et al. 2001). For PM_{10} concentrations above 10 μg/m^3 in Mazzano and Rezzato (Italy), the number of excess cases of respiratory mortality was calculated to be about 0.7 persons (Fattore et al. 2011). In the USA, each 10 μg/m^3 increase of PM_{10} concentration up to 150 μg/m^3 caused 0.12% increase in the risk rate of mortality among inhabitants of San Jose during 1980-1986 (Fairley 1990).

For PM_{10} lower than 100 μg/m^3, every 10 μg/m^3 increase in PM_{10} level led to 1.1% increase in mortality risk in Los Angeles, USA (Shumway et al. 1988). In Egypt, an increase of 4.1% in the hospital visits was reported due to respiratory disease and was associated with an increase of 10 μg/m^3 in the PM_{10} level (Shakour et al. 2011). In a cohort study in 25 cities in China, increases of 1.8% (95% CI: 0.8-2.9%) and 1.7% (95% CI: 0.3-3.2%) in mortality risk per 10 μg/m^3 increment of PM_{10} level were observed for cardiovascular and respiratory mortality, respectively (Zhou et al. 2014b). The results of this study showed that about 4.9% of the COPD occurred for PM_{10} concentrations higher than 200 μg/m^3, and 7.3% of RM was attributed to PM_{10} concentrations exceeding 200 μg/m^3. In Trieste (Italy), t] results showed that 2.5% of respiratory death can be related to PM_{10} levels over 20 μg/m^3 (Tominz et al. 2005). Finally, our study shows that most of the people were admitted to hospitals when the PM_{10} concentrations were above 200 μg/m^3. These high values can be attributed to Middle Eastern Dust events.

5. **Conclusions**

The relevance of dust storms to public health will increase since extreme weather events are predicted to become more frequent through the 21st century (Crooks et al. 2016). Our study was the first to assess the impact of PM_{10} on hospital visits for COPD and RM in Ilam, Iran. The results demonstrate the impact of the Middle-Eastern Dust (MED) events in Ilam on the increase in hospital visits due to COPD and RM attributable to PM_{10}. Exposure to PM (particularly MED) is likely causing excess hospital admissions for COPD and an excess of the respiratory mortality. Those outcomes should encourage regulators to implement cost-effective clean air policies. In order to reduce the harm caused by MED, simple and effective actions can be recommended. For example, specific health prevention advice should be offered to all people affected by these storms (particularly elderly, children, and people with pre-existing heart conditions) in order to limit their daily activities during dusty days. Additionally, strategic management of water bodies and planting new plant species, or green infrastructure implementation in urban areas, could be effective in mitigating the impacts of desert dust on respiratory conditions.

Conflicts of interest

All authors declare that they have no any competing interests.

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