Modeling Particulate Matter (PM₁₀) in Makkah, Saudi Arabia - A View Point of Health Impact

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Abstract—The core aim of this paper is to investigate the health impacts of PM₁₀ in Makkah (March 2012 to February 2013). The annual average of PM_{10} concentration was 195 $\mu g/m^3$, which is greater than both EC and PME annual standards. Daily average concentrations also exceeded PME and EC standards. Furthermore, health assessment is carried out using AirQ2.2.3 model to estimate the number of hospital admissions due to respiratory diseases. The cumulative number of average hospital admission due to respiratory illnesses during the study period was 112665, cumulative number of cases per 100,000 was 2504 and the concentrationresponse coefficient was 2.342 (95% CI 1.899 - 2.785) per 10 $\mu g/m^3$ increase of PM₁₀. The violation of daily and annual air quality standars and the results of AirQ2.2.3 suggest potential negative health impact for the residents, especially for more vulnerable groups, such as old aged, children and people with asthma and other respiratory diseases.

Index Terms—Air pollution, exceedences, health effects, makkah.

I. INTRODUCTION

Particulate matter can be categorized into primary and secondary aerosols: i) Primary aerosols include emission from pilot power plants, auto mobile exhaust, sea spray, and dust storm, and are emitted into the atmosphere directly from the source. ii) Secondary aerosols are produced in the atmosphere from reactions involving primary or secondary gases [1]-[3].

Airborne particles, especially fine particles are found to be widely associated with health problems, [4], [5]. Rapid industrialization and urbanization in the past decade has resulted in a world-wide increase of airborne particulate matters [6], which are responsible for the reduction in visibility in urban areas [7] and can adversely affect human health [8]. The suspended particles are introduced directly into the atmosphere by natural causes, e.g. sea spray and erosion, volcanic eruptions, as well as other sources like the anthropogenic pollution sources [9], [10]. As they evolve in the atmosphere, their chemical and physical characteristics change. Such changes are carried out by atmospheric gas phase chemical reactions or through heterogeneous reactions with other gaseous species. The physical characteristics of airborne particulate matter, such as size distribution and mass concentration of the dust are more

often associated with the incidence of health hazard. In recent decades, suspended particulate matter (PM₁₀ and $PM_{2,5}$ have received much attention due to its potential adverse health impact and the subsequent need to better control or regulate these pollutants. The sources, characteristics and potential health effects of PM₁₀ and PM 2.5 are very different from each other; the latter can penetrate into the lungs more readily and is therefore more likely to increase respiratory and mutagenic diseases [11]. Particle shape and size are critical factors controlling the extent to which particles can penetrate into the respiratory tract, how and where particles are deposited, and at what rate particles are cleared form respiratory tract. Furthermore, a large number of smaller particles have a greater reactive surface area than an equivalent mass of larger particles and have a higher likelihood of reaching the deepest regions of the lungs, namely the alveolar region. Ultrafine airborne particles below 1 µm in diameter have been related to premature death, aggravated asthma, increased hospital admissions, and increased respiratory problems [12], [13].

There is a strong link between elevated particle concentration and increased mortality and morbidity [14]. Exposure to particulate matter can aggravate chronic respiratory and cardiovascular diseases, alter host defenses, damage lung tissue, lead to premature death, and possible contribute to cancer [12], [14]. Moreover, in order to understand exposures to contaminants and its associated results on health impacts [15], we need to evaluate: 1) the type of viable and nonviable particles; 2) the various sources of contaminants and the physicochemical factors leading to exposures; 3) the chemical nature of the complex mixtures in the air and the atmospheric physical (including meteorological) interactions; 4) the nature and mechanisms of the morbidity effects associated with the contaminants, including the range and distribution of sensitivity in the population; and 5) the methods of evaluation.

The main aim of this research is to study the health impacts of particulate matter with aerodynamic diameter of 10 micron or less (PM_{10}) in Makkah from March 2012 to February 2013. Higher activities of pilgrims in Hajj and Umrah season can also lead to increase particulate concentrations, generated from traffic emission, fuel evaporations, aerosols transfer and various anthropogenic activities in Makkah City. Furthermore, the current study use AirQ2.2.3 model to estimate the number of hospital admissions due to respiratory diseases for each concentration range and each relative risk for the sampling site.

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II. MATERIALS AND METHODS

A. Study Area

The Holy City of Makkah (Latitude 21° 25' 19" North Meridian 39° 49' 46") is at an elevation of 277 m above sea level, and approximately 80 km inland from the Red Sea. The city is situated between mountains, which have defined the contemporary expansion of the city with a population of 1,700,000 (CDSI, 2010). The city of Makkah centers around the Holy Mosque (Al-Haram), which is lower than most of the city. The area around Al-Haram comprises the old city. Transportation facilities, either personal vehicles or private taxis, related to the Hajj and/or Umrah are the main services available around the city. The mobile laboratory for air quality in Makkah city was placed in Misfalah site, which is about 2 km far from the Holy Mosque (as shown in Fig. 1). The automatic continuous monitoring of PM₁₀ was carried out during the year 2012 to represent the whole activities in the central areas of Makkah city. The respirable particulate matters (PM₁₀) were recorded by continuous IP Beta Gage Monitor device.



Fig. 1. Map of Misfalah station in Makkah.

B. AirQ2.2.3 Model Inputs

The AirQ2.2.3 model is based on a risk assessment approach, which combines data on concentration-response functions with data on population exposure to calculate the extent of health effects expected to result from exposure to a particulate matter (here PM_{10}). The information on concentration-response functions is provided by WHO [16], obtained from the epidemiological literature and expressed as relative risk for several health effects, such as premature mortality or hospital admission. Data on population exposure comprise population data, incidence rates for specific health effect and air quality data. The user has to provide the data on population exposed to air pollution. The model needs the following input data :

- 1) Personal data such as (country name, year of study, address of the area of investigation, city name, email and telephone number of user and responsible person).
- 2) Pollutant data such as type of pollutant (in this study pollutant considered was PM_{10}), Makkah city coordinates (Latitude 21.43N and Longitude 39.82E), exposed population (2700000 pilgrim +1800000 resident) and number of stations used for profile (1) (Makkah, 2012).

- 3) Air quality data such as mean and maximum (for each site) and cumulative concentrations which ranged from $< 10 \ \mu g/m^3$ to $>= 400 \ \mu g/m^3$.
- 4) Calculate Relative Risk (RR) manually using the following equation:

 $RR = \exp \left[B(X-Xo)\right] \qquad (WHO, 2004)$

where B = 0.0006 - 0.0010 (mean 0.0008)

 $X = Annual mean PM_{10}concentration (\mu g/m^3)$

- Xo = Baseline (Threshold) concentration ($\mu g/m^3$)
- 5) In this equation low, high and the mean value of constant B were used to estimate low, high and mean relative risk. Furthermore, instead of baseline concentration, annual air quality standard of PME for PM_{10} was ued, which is 80 µg/m³. The following information were also required to run the model: Health data such as health end point (hospital admissions due to respiratory diseases), baseline incidence (3872 case per 100000 person per year) [17], relative risk (mean, lower and upper) from previous equation, and scientific certainty of relative risk.

C. AirQ2.2.3 Model Output

AirQ2.2.3 model estimates impacts such as cumulative number of cases per 100,000 persons for each concentration range and each relative risk for each site and calculates hospital admissions due to respiratory diseases.

Month	Mean	Max.	Min.	St. Dev.	
January	276.0	549.8	114.2	123.7	
February	231.0	360.3	66.1	74.5	
March	149.0	259	89.0	6.4	
April	234.1	573.3	86.0	121.4	
May	239.1	421.2	129.7	76.0	
June	191.3	493.8	76.8	132.0	
July	201.7	782.1	102.1	145.6	
August	138.5	230.3	74.2	45.2	
September	159.4	296.0	100.6	61.9	
October	180.6	248.9	95.9	39.8	
November	152.1	217.6	98.2	31.8	
December	166.9	257.2	102.3	37.4	
Annual	195.5	782.1	66.1	96.3	

TABLE I: RESPIRABLE PARTICULATE MATTER (PM10) 24 HOUR AVERAGE CONCENTRATIONS (μ G/M3) AT MISFALAH SITE IN MAKKAH DURING 2012

III. RESULTS AND DISCUSSIONS

Table I shows the descriptive statistical analysis of respiratory particulate matter (PM_{10}) concentrations at Misfalah sites in Makkah city for one year period (from March 2012 to February 2013). This table indicates significant seasonal variation in PM_{10} concentrations. Maximum concentration of PM_{10} was recorded during summer season in month of July (782 µg/m³), whereas, the minimum value was recorded during winter in the month of February (66 µg/m³). Higher concentration in summer is probably caused by high wind speed and high temperature a common phenomenon in Saudi Arabia which increases atmospheric turbulence leading to a greater amount of

resuspension of dust from roadside and blowing sand particles from the surrounding areas. It is worth mentioning that resuspension of dust particles and windblown sand and dust particles along with road traffic and other combustion processes are the main sources of particulate matter in Saudi Arabia [18], [19]. However the model does not differentiate in PM_{10} originated from different sources.

Exposure to high concentrations of air pollutants can adversely affect human health. National and international organizations (e.g., WHO, European Union and, the Saudi Arabian Presidency of Meteorology and Environment -PME) have established health based standards and objectives for a number of air pollutants. These standards apply over different periods of time because the observed health impacts associated with the various pollutants occur over different exposure times. EC (European Commission) has established annual average (40 μ g/m³) and 24 hour average (50 μ g/m³, not to be exceeded more than 35 time a year) standards for PM₁₀ concentration. Air quality standard for PM₁₀ established by PME are 340 μ g/m³ and 80 μ g/m³ for 24 hour and annual average, respectively. It is generally believed that when PM₁₀ concentrations exceed these standards adverse health impacts are expected, according to the current scientific understanding. However, it is worth mentioning that WHO has not established a minimum concentration for PM₁₀ below which adverse health impact is not likely because according to some evidences particulate matter can cause health impact at any level and that the impact is more relevant with particle composition and size than the concentration level [20].

 PM_{10} concentrations observed in Makkah during March 2012 to February 2013 are compared with the air quality standards. The annual average of PM_{10} concentration during the study period was 195.5 μ g/m³, which is greater than both EC and PME annual standards. The observed concentration is greater than twice the PME standards and 4 times greater than the EC standard. This suggests potential negative impact on human health and long term health problem for the residents, especially for more vulnerable groups of population, such as old age, children and people with other health problems (e.g., asthma and other respiratory diseases).

When 24 hour average PM_{10} concentration was compared with the air quality standard established by PME, the number of exceedences was 29 (Fig. 2). Comparison of 24 hour average PM_{10} concentration showed that every single day the concentration was greater than the EC limit. Minim 24 hour average concentration was 66 µg/m³, which is significantly greater than the EC limit of 50 µg/m³. This again shows that PM_{10} concentration in Makkah is a potential risk for human health. Sources apportion of particulate matter in Makkah is required to characterise emission sources and analyse the composition of particulate matter.

The result of AirQ2.2.3 model is presented in Table II. The model combines data on pollutant concentrationresponse functions with data on population exposure to calculate the extent of health effects due to respiratory diseases, expected to result from exposure to PM_{10} concentrations. PM_{10} hospital admissions due to respiratory disease at Misfalah in Makkah city during the year 2012 (March 2012 to Feb 2013) are shown in Table II, which shows different parameters, such as % person-days (personday is the amount of work done by one person in one working day), cumulative (cum.) number of cases, cumulative number of % cases etc. for average relative risk (1.096). In Table II the zero values on top indicate presence of no data below 60 µg/m³ as minimum values was 66.1 $\mu g/m^3$. The highest number of cases per 10 $\mu g/m^3$ increase were estimated for PM₁₀ concentration from 170 to 179 $\mu g/m^3$. It should be noted that in Table II the concentration steps are larger (50 instead of 10 μ g/m³) at the end (from 200 to 400 μ g/m³). Fig. 3 shows cumulative number of excess cases for minimum, mean and maximum relative risk values. It is indicated that the risk of PM₁₀ increased as PM₁₀ concentration increased, which is expected. Total cumulative number of cases estimated for the study period was 112665, whereas cumulative number of cases per 100,000 was 2504 in Makkah. Table II shows that theconcentration-response coefficient was 2.342 (95% CI 1.899 - 2.785) at Misfalah site per 10 μ g/m³ increase of PM₁₀. This value is lower than that measured in Cairo -Egypt 4.1% (95% CI 4.1-4.2%), whereas it is higher than those recorded in Shanghai-China 0.23% (95% CI: -0.03%, 0.48%), in Tallinn, Estonia 1.14% (95% CI 0.62-1.67%) and in northern China 0.036% (0.012-0.06%) [21]-[26].



Fig. 2. Daily (24 hour) average PM₁₀concentration (μg/m³) in Makkah from March 2012 to February 2013. The red asterisks show exceedences of air quality limits (340 μg/m³) set by PME (Presidency of Meteorology and Environment of Saudi Arabia).

The health impact assessment using concentration response functions provides general idea about the pollutants level and their potential adverse impact, however this sort of approaches come with several uncertainties, which need to be considered before making any conclusion. Some of the uncertainties are mentioned here [20]: (a) It is not possible to accurately determine population exposure to ambient air pollutants as there is often limited knowledge of time-activity patterns and therefore pollutant concentrations are considered as exposure level. (b) There are many epidemiological studies characterising concentrationresponse functions, however all of these, including the one used in this study are associated with confounding factors and statistical uncertainties. (c) This study uses a threshold level of 80 μ g/m³ suggested by PME, assuming no health effect occurs below this level. However, quantifying the health effects of ambient air pollution is related to the issue of whether or not there is a threshold for ambient air pollutant health effects. Many epidemiological studies are now demonstrating adverse health effects at levels of air pollutants well below published air quality standards. Therefore, it has been suggested that a threshold may not

exist below which levels there are no health effects.Health impacts are affected by local meteorological conditions, therefore concentrations-response functions developed in one part of the world may not be applicable in another part.

Further work is required to carry out a detailed health impact investigation of PM_{10} and $PM_{2.5}$ in Makkah using data from multi-locations. Source apportionment of particulate matter is required to identify various sources and their percent contribution and investigate their health impact in Makkah.

	CONCENTRATION-	RESPONSE COEFFIC	JENT WITH 95% CIV	WAS 2.34 (1.899 - 2.)	785) PER 10 MG/M ⁻ I	NCREASE OF PM_{10} .	
$\mu g/m^3$	% Person-Days	¹ Cum. %	NO. of cases	Cum. NO.of cases	Cases (%)	Cum. %	Cum.per 100 000
<10	0	0	0	0	0	0	0
10-19	0	0	0	0	0	0	0
20-29	0	0	0	0	0	0	0
30-39	0	0	0	0	0	0	0
40-49	0	0	0	0	0	0	0
50-59	0	0	0	0	0	0	0
60-69	0.32	0.32	106	106	0.09	0.09	2.4
70-79	0.32	0.65	125.3	231.3	0.11	0.21	5.1
80-89	0.97	1.62	433.6	664.9	0.38	0.59	14.8
90-99	3.25	4.87	1638.1	2303	1.45	2.04	51.2
100-109	5.52	10.39	3112.5	5415.5	2.76	4.81	120.3
110-119	7.14	17.53	4451.9	9867.3	3.95	8.76	219.3
120-129	5.19	22.73	3546.1	13413.4	3.15	11.91	298.1
130-139	7.47	30.19	5540.7	18954.2	4.92	16.82	421.2
140-149	5.19	35.39	4162.8	23117	3.69	20.52	513.7
150-159	6.17	41.56	5309.5	28426.4	4.71	25.23	631.7
160-169	5.52	47.08	5078.2	33504.7	4.51	29.74	744.5
170-179	7.79	54.87	7631.8	41136.4	6.77	36.51	914.1
180-189	4.87	59.74	5058.9	46195.4	4.49	41	1026.6
190-199	6.49	66.23	7130.7	53326.1	6.33	47.33	1185
200-249	17.53	83.77	24456.4	77782.4	21.71	69.04	1728.5
250-299	4.55	88.31	7689.6	85472	6.83	75.86	1899.4
300-349	2.6	90.91	5164.9	90637	4.58	80.45	2014.2
350-399	4.87	95.78	11129.7	101766.6	9.88	90.33	2261.5
>=400	4 22	100	10898.4	112665	9.67	100	2503 7

TABLE II: OUTPUTS OF AIRQ2.2.3 MODEL PER 10 DEGREES INCREASE IN PM₁₀ CONCENTRATION (μG/M3) IN MAKKAH, USING MEAN RR (1.0964). CONCENTRATION-RESPONSE COEFFICIENT WITH 95% CI WAS 2.34 (1.899 - 2.785) PER 10 MG/M³ INCREASE OF PM₁₀.

In the Table cum. stands for cumulative and RR stands for relative risk.



Fig. 3. Number of Hospital admissions due to respiratory diseases per 100000 people.

IV. CONCLUSION

In this paper PM_{10} concentration in Makkah is analysed and compared with air quality standards. PM_{10} levels in Makkah exceed national and international air quality standards set for the protection of human health, therefore pose potential threat to human health, particularly the more vulnerable groups of population, such as old people, children and those with long term health problems. The AirQ2.2.3 model is proposed by WHO for health impact assessment of air pollutant and is based on concentrationresponse function. This study is the first attempts to apply the AirQ2.2.3 model to provide quantitative data on the impact of particulate matter exposure on the health of people living in Makkah City, KSA during 2012 (1433H). The results of the model are discussed and compared with several studies conducted in other countries around the world. In spite of several uncertainties, this approach successfully highlights the potential risk of air pollutants to human health.

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