Health Impacts of PM_{10} Using AirQ2.2.3 Model in Makkah

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Abstract: The core aim of this paper is to investigate the health impacts of atmospheric particles with aerodynamic diameter of 10 micron or less (PM_{10}) in Makkah. PM_{10} data were collected by automatic continuous monitoring station in Misfalah, Makkah City. The annual average PM_{10} concentration during the study period was 195 µg/m^3, which is greater than twice the PME standards and 4 times the EC standard. Daily average concentrations also exceeded PME and EC standards. Minimum 24 hour average concentration was 66 µg/m^3, which is significantly greater than the EC daily average limit (50 µg/m^3). This suggests potential negative impact on human health, 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). Furthermore, health assessment is carried out using AirQ2.2.3 model to estimate the number of hospital admissions due to respiratory diseases. The model is based on a risk assessment approach that combines data on concentration-response functions with data on population exposure to calculate the extent of health effects expected to result from exposure to PM_{10}. The cumulative number of estimated average hospital admission due to respiratory illnesses during the study period was 112665, cumulative number of cases per 100,000 was 2504, and the concentration-response coefficient was 2.342 (95% CI 1.899 – 2.785) per 10 µg/m^3 increase of PM_{10} concentration. The results are discussed in the light of investigations made in several other countries around the world.

Keywords: Health effects, air pollution, exceedences, AirQ2.2.3 model, Makkah, PM_{10}.

1. INTRODUCTION

Airborne suspended particulate matter is an important marker of air quality. Particles are usually emitted into the atmosphere from numerous natural and man-made sources. They are also formed upon condensation of gases and vapours [1-3]. Anthropogenic airborne particulate matter comes from a variety of sources which include traffic, industries, commerce and domestic heating and cooking [4]. Particles can be classified based on their aerodynamic diameter into; (1) coarse particle fraction, where the aerodynamic diameter is larger than 2.5 µm, (2) fine particle fraction, where the particles have an aerodynamic diameter less than 2.5 µm, and (3) ultra fine particles where the aerodynamic diameter is less than 0.1µm . The coarse fraction are usually emitted from crustal material, paved road dust, non-catalyst equipped gasoline engines and back-ground sea salts, while the fine fraction is emitted from anthropogenic rather than natural sources or formed by vapour nucleation/condensation mechanisms [2]. The lifetime of particulates varies from a few seconds to several months, depending upon their settling rate, size, density, and air turbulence. Clouds of very fine particles may drift for hundreds to thousands of kilometers and may cause pollution at large distance from where they were emitted. Coarse particles, on the other hand, travel for tens of kilometers or less [5]. The larger size particles are greatly affected by gravity while the fine ones are more affected by diffusion [2, 6].

Particulate matter can be categorized into primary and secondary aerosols: i) Primary aerosols include emission from pilot power plants, automobile 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 [5, 7, 8].

Airborne particles, especially fine particles are found to be widely associated with health problems [9, 10]. Rapid industrialization and urbanization in the past decade has resulted in a world-wide increase of airborne particulate matters [11], which are responsible for the reduction in visibility in urban areas [12] and can adversely affect human health [13]. 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 [14, 15]. As they evolve in the atmosphere, their chemical and physical characteristics change. Such changes are carried out by atmospheric gas phase chemical reaction 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 (PM_{10} and $PM_{2.5}$) have

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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 PM_{10} 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 [16]. 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 from 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 [2].

Many of the recent studies have indicated that out of all pollutants in a typical urban environment, airborne particulate matter, specially the fine and ultra-fine particles, could be the most closely related to many of the health end points [17, 18]. Many epidemiological studies found that there is a statistical association between health outcomes and particulate matter concentrations. Studies revealed that fine particles are considered to be responsible for respiratory health effects rather than the coarse ones. The debate over the scientific evidence for an underlying cause linking the level of airborne particles to adverse health effects has been intensified in recent years.

Table **1** shows air quality standards for PM_{10} set by various organizations, which are compared with concentrations to calculate exceedences. WHO [19] suggested that in order to understand exposures to contaminants and its associated results on health impacts, 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. 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.

2. MATERIALS AND METHODS

2.1. Study Area

The Holy City of Makkah (Latitude 21° 25′ 19″, North Meridian 39° 49′ 46″) is at an elevation of 277 m (910 ft) above sea level, and approximately 50 mile (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 [26]. The city of Makkah centers around the Holy Mosque (Al-Haram), which is lower than most of

Table 1: Ambient Air Quality Limit Values as Given by Kingdom of Saudi Arabia compared to Reference Standards and Guidelines for Average Ambient Particulate Concentration (μg/m^3)

Standard or Guideline	(Annual)		(24 Hours)	
	PM_{10}	TSP	PM_{10}	TSP
Kingdom of Saudi Arabia	80	-	340	-
EU limit values	40	150	50	300
USEPA primary and secondary standards	50	-	150	-
WHO guidelines	-	60-90	-	150-230
WHO guidelines for Europe	50	70	125	-
National Ambient Air Quality Standards	-	-	150	-
Egyptian limit	70	90	-	230

Source: [19, 20-25].

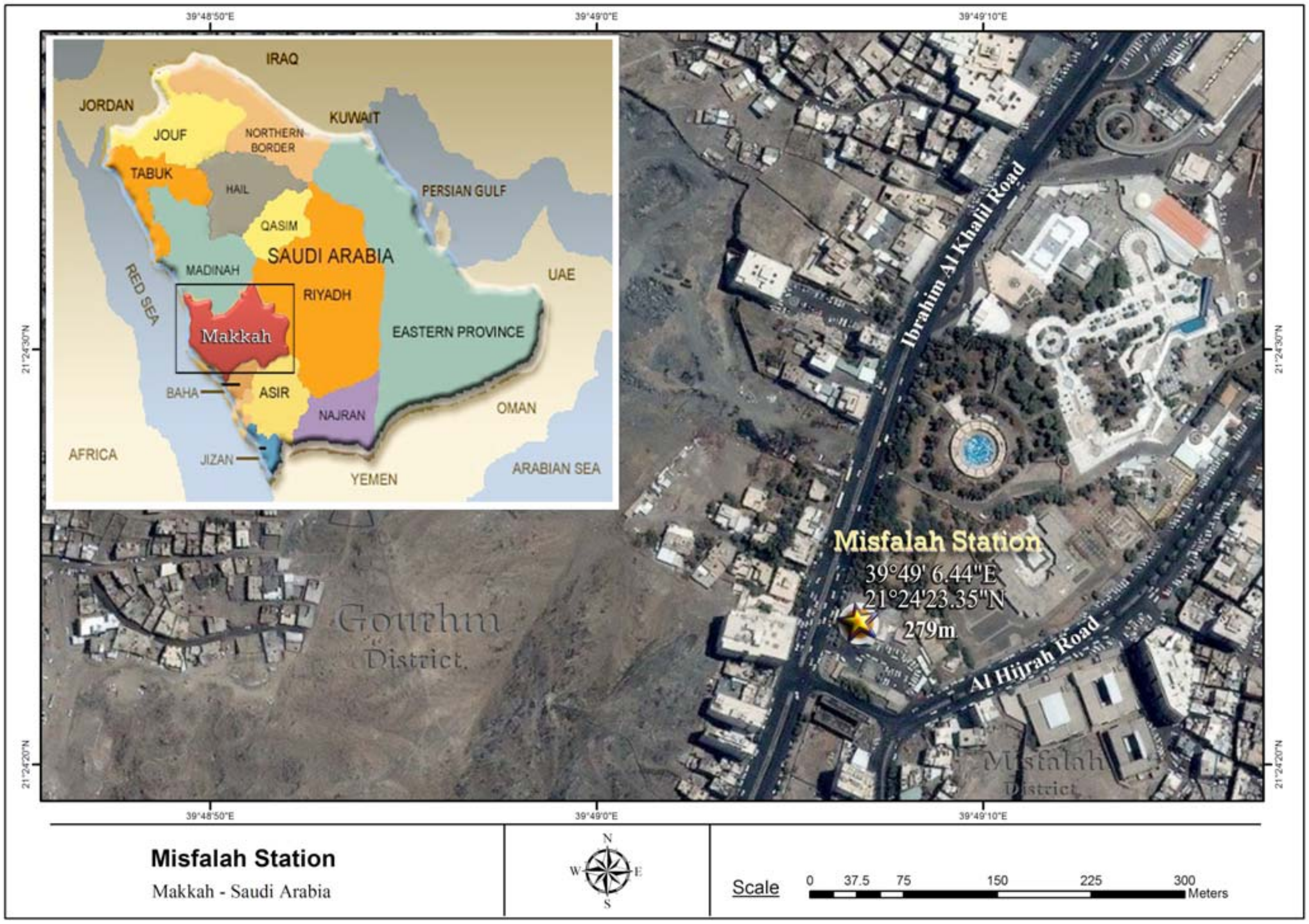

Figure 1: Map of Misfalah station in Makkah city.

the city. The area around the Holy Mosque (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 2km far from the Holy Mosque (as shown in Figure **1**). The automatic continuous monitoring of PM_{10} was carried out for a one year period (March 2012 to February 2013) to represent the whole activities in the central areas of Makkah city. PM_{10} concentrations were recorded by Continuous IP Beta Gage Monitor device (Figure **2**).

2.2. AirQ2.2.3 Model Inputs (WHO, 2010)

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 particulate matter (here PM_{10}). The information on concentration-response functions is provided by WHO 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

Figure 2: Continuous monitoring devices inside Misfalah station.

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) [27]

3. Air quality data such as mean and maximum (for each site) and cumulative concentrations which ranged from < 10 μg/m^3 to >= 400 μg/m^3 were input to program then calculated the health impact.

4. Calculate Relative Risk (RR) manually using the following equation:

   $RR = \exp [B(X-Xo)]$ [18]

Where B = 0.0006 – 0.0010 (mean 0.0008)

X = Annual mean concentration (μg/m^3)

Xo = Baseline (Threshold) concentration (μg/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, we used annual air quality standard of PME for PM_{10}, which is 80 μg/m^3. The following information were 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) [28], relative risk (mean, lower and upper) from previous equation, scientific certainty of relative risk calculate impact of concentrations > 10 ug/m^3, calculate impact estimates to estimate number of excess cases for mean, lower and upper relative risk.

2.3. AirQ2.2.3 Model Outputs

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 PM_{10} 2012 hospital admissions respiratory diseases.

3. RESULTS AND DISCUSSION

Table **2** shows the descriptive statistical analysis of PM_{10} concentrations at Misfalah sites in Makkah city for the study 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 July (782 μg/m^3), whereas, the minimum value was recorded

Table 2: PM_{10} 24 hour Average Concentrations (μg/m^3) at Misfalah Site in Makkah from March 2012 to February 2013

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

during winter in February (66 μg/m^3). 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 [29-30]. 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 pollutants in air. 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 μg/m^3) and 24 hour average (50 μg/m^3, not to be exceeded more than 35 time a year) standards for PM_{10} concentration. Air quality standard for PM_{10} established by PME are 340 μg/m^3 and 80 μg/m^3 for 24 hour and annual average, respectively. It is generally believed that when PM_{10} 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 PM_{10} 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 [31].

The annual average of PM_{10} concentration during the study period was 195.5 μg/m^3, which 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 (Figure **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/m^3, which is significantly greater than the EC limit of 50 μg/m^3. 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 results of AirQ2.2.3 model integrated data on pollutant concentration-response 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 a one year period: March 2012 to Feb 2013 are shown in Table **3**, which shows different parameters, such as % person-days (person-day 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 **3** the zero values on top indicate presence of no data below 60 μg/m^3 as minimum values was 66.1 μg/m^3. The highest number of cases per 10 μg/m^3 increase were estimated for PM_{10} concentration from 170 to 179 μg/m^3. It should be noted that in Table **3** the concentration steps are larger (50 instead of 10 μg/m^3) at the end (from 200 to 400 μg/m^3). Figure **3** shows cumulative number of excess cases for minimum, mean and maximum relative risk values. It is indicated that the risk of PM_{10} increased as PM_{10} 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 **3** shows that the concentration-response coefficient was 2.342 (95% CI 1.899 – 2.785) at Misfalah site per 10 μg/m^3 increase of PM_{10}. 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%) [32-38].

Several studies have examined the association between PM_{10} and respiratory hospital admissions. The respiratory hospital admission were estimated in different countries over the world: 2003 case in Malaysia, 1240 case in China, 8970 case in USA per 100,000 people [32, 39-42]. Guo *et al*. [34-35] and Chen *et al*. [37] found that PM_{10} was significantly

Table 3: Outputs of AirQ2.2.3 Model Per 10 Degrees Increase in PM_{10} Concentration (μg/m^3) in Makkah, Using Mean RR (1.0964). Concentration-Response Coefficient with 95% CI was 2.34 (1.899 – 2.785) per 10 μg/m^3 Increase of PM_{10}

μg/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

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

associated with total respiratory hospitalization with RRs of 1.14 (95% CI: 1.01, 1.29) and it was stronger in the cool season (from November to April) than in the warm season (from May to October). Table **4** reports a brief description of the locations of sampling points over the world, the obtained concentrations for PM_{10} and the expected effects or risk results.

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 [31]: (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 concentration-response functions, however all of these concentration-response functions, including the one used in this study are associated with confounding factors and statistical uncertainties. (c) This study uses a threshold level of 80 μg/m^3 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

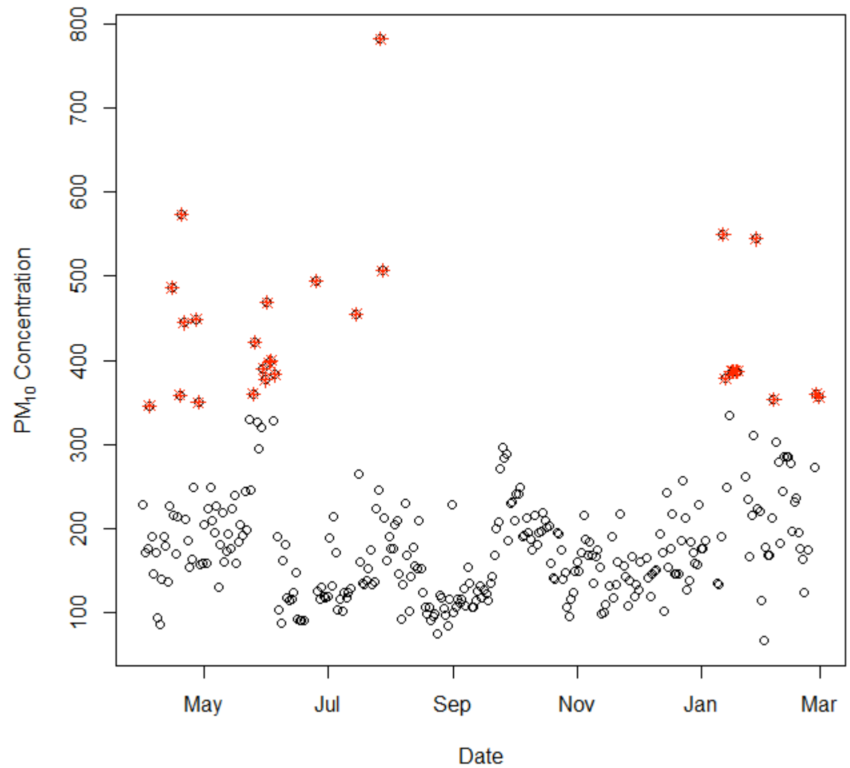

Figure 3: Daily (24 hour) average PM_{10} concentration (μg/m^3) in Makkah from March 2012 to February 2013. The red asterisks show exceedences of air quality limits (340 μg/m^3) set by PME (Presidency of Meteorology and Environment of Saudi Arabia).

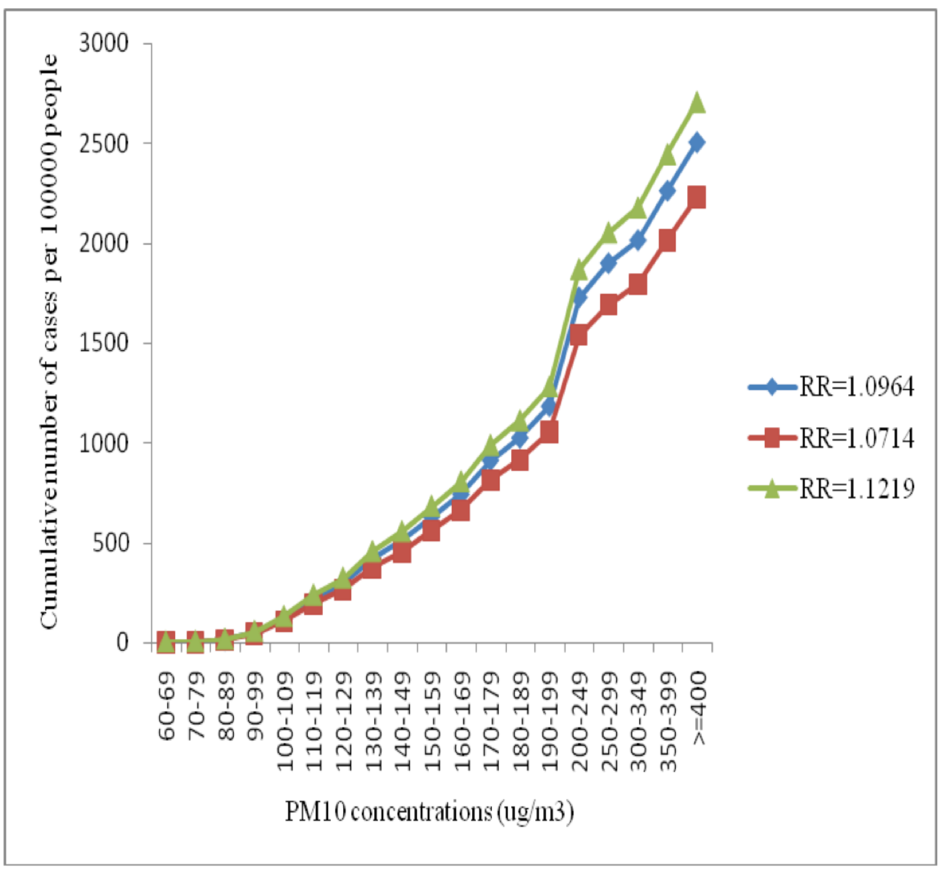

Figure 4: Number of Hospital admissions due to respiratory diseases per 100000 people.

Table 4: Quantitative Relationship of Short-Term Exposure to Daily Mortality

Location	24h exposure of PM_{10} (μg/m^3)	Results	Reference
Salt lake city, UK, USA	47 - 297	Significant increase in mortality (50 – 100 ug/m^3) – 7.5%	[43]
Salt lake city, UK, USA	47 - 297	No Significant increase overall; some increase in the elderly	[44]
Athens	78 – 306	Significant 3.4%increase in mortality (50 – 100 ug/m^3)	[45]
San Jose and other CA areas, USA	<150	0.12% increase in mortality per increase of 10 ug/m^3 PM_{10}	[46]
Los Angeles and other CA areas, USA	>100	1.1% increase in mortality per increase of 10 ug/m^3 PM_{10}	[47]
Los Angeles and other CA areas	>100	No increase in total or cause-specific mortality	[48]
Los Angeles and other CA areas	58 – 177	No increase in total or cause-specific mortality	[49]
St. Louis, MO, USA	28 – 97	Significant 8%increase in total mortality (50 – 100 μg/m^3)	[50]
Kingston, TN, USA	30 – 67	No significant increase in mortality	[51]
Birmingham, AL, USA	48 – 163	Significant 5%increase in total mortality (50 – 100 μg/m^3)	[16]
Toronto, Canada	40 – 96	Significant 2.5%increase in total mortality (50 – 100 μg/m^3)	[52]
Chicago, IL, USA	38 – 128	Significant 2.5%increase in total mortality (50 – 100 μg/m^3)	[53]
Chicago, IL, USA	37 – 365	No significant increase in total mortality	[54]
Santiago, Chile	115 – 367	Significant 2.6 - 7%increase in total mortality (50 – 100 μg/m^3)	[55]

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.

4. CONCLUSIONS

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. This study is the first attempt 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 a one year period (March 2012 to Feb 2013). Total cumulative number of cases estimated for the study period was 112665, cumulative number of cases per 100,000 was 2504, and the concentration-response coefficient was 2.342 (95% CI 1.899 – 2.785) per 10 μg/m^3 increase of PM_{10}. 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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