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Risk Assessment of Particulate Matter (PM_{10}) in Makkah, Saudi Arabia

Turki M. Habeebullah, Atef M. F. Mohammed, Essam A. Morsy

***Abstract*—**In recent decades, particulate matter (PM_{10}) have received much attention due to its potential adverse health impact and the subsequent need to better control or regulate these pollutants.

The aim of this paper is focused on study risk assessment of PM_{10} in four different districts (Shebikah, Masfalah, Aziziyah, Awali) in Makkah, Saudi Arabia during the period from 1 Ramadan 1434 AH - 27 Safar 1435 AH. Samples were collected by using Low Volume Sampler (LVS Low Volume Sampler) device and filtration method for estimating the total concentration of PM_{10}.

The study indicated that the mean PM_{10} concentrations were 254.6 (186.1 - 343.2) µg/m^3 in Shebikah, 184.9 (145.6 - 271.4) µg/m^3 in Masfalah, 162.4 (92.4-253.8) µg/m^3 in Aziziyah, and 56.0 (44.5 - 119.8) µg/m^3 in Awali. These values did not exceed the permissible limits in PME (340 µg/m^3 as daily average). 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 cases per 100,000 were 1534 (18-3050 case), which lower than that recorded in the United States, Malaysia. The concentration response coefficient was 0.49 (95% CI 0.05 - 0.70) per 10 µg/m^3 increase of PM_{10}.

***Keywords*—**Air pollution, Respiratory diseases, AirQ2.2.3, 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 physical characteristics of airborne particulate matter, such as size distribution and mass concentration of the dust are more It is known that particulate matter is an important marker for measuring air quality, as evidence of their presence and the presence of contaminants in the air. Particles are formed in the atmosphere from natural and artificial sources, also made up of condensation of gases and vapors in the air [8]-[10]. Particulate matter, especially inhaled dust (less than 10 microns) spread to the atmosphere from a variety of sources, including vehicular traffic, industrial processes, home heating, and cooking [11].

Most of the health damage caused by exposure to particles suspended caused by nanoparticle at a young age, less than 10 ppm and penetrate these particles way until you reach the lung, causing different symptoms such as asthma, cough etc. (Fig. 1).

Most of these suspended particles be the result of incomplete combustion include ash, soot and carbon compounds. In addition to the suspended particles is comprising acidic condensates and metals such as lead, cadmium sulfate and nitrate. If the amount of dust or particles that reach the respiratory tract in the acceptable limits it is possible to get rid of 95% of them by the defense systems of the respiratory system.

In recent decades, PM_{10} have received much attention due to its potential adverse health impact and the subsequent need to better control or regulate these pollutants. PM_{10} can penetrate into the lungs more readily and is therefore more likely to increase respiratory and mutagenic diseases [11]. 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], [13].

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.

The main aim of this research is to study the risk asessment of particulate matter with aerodynamic diameter of 10 micron or less (PM_{10}) in four districts in Makkah, Saudi Arabia: Shebikah, Masfalah, Aziziyah, and Awali during the period from 1 Ramadan 1434 AH 27 to Safar 1435 AH. 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.

II. Material and Methods

A. Study Area and Sampling Description

The Holy City of Makkah (Latitude 21° 25′ 19″ North, longitude 39° 49′ 46″) is at an elevation of 277 m above sea

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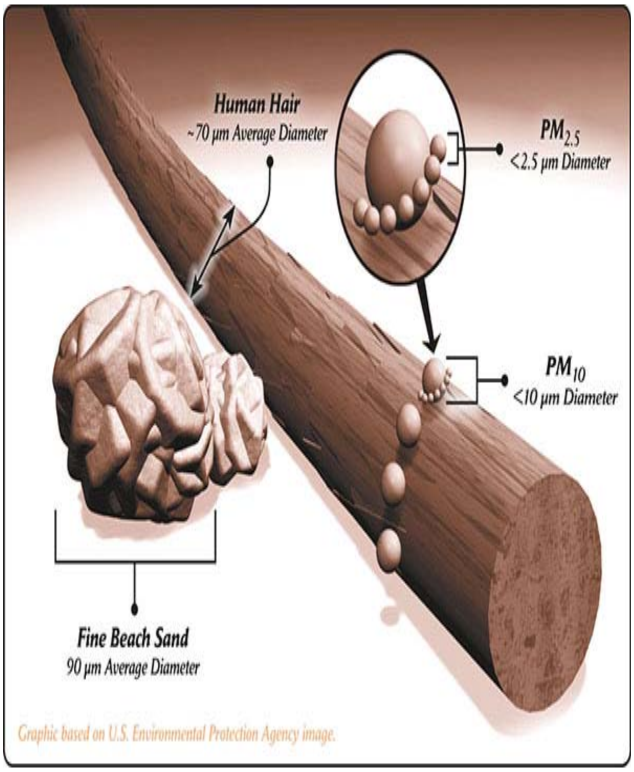
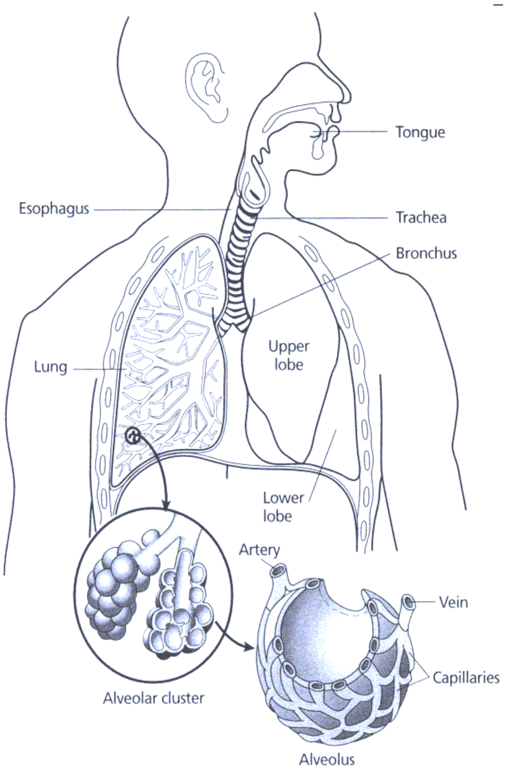
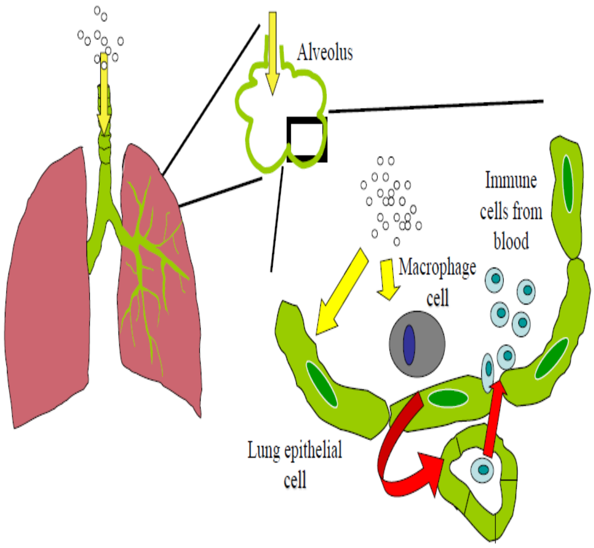
level, and approximately 80 km inland from the Red Sea. The city is situated between mountains, which have defined the contemporary expansion of the city with a population of 1,700,000 [14]. The area around Al-Haram comprises the old city. Transportation facilities, either personal vehicles or private taxis, related to the Hajj and/or Umrah are the main services available around the city. Sampling locations included four different districts: i) Shebikah in the central region near Al-Haram. ii) Masfalah District is characterized by high traffic densities. iii) Aziziyah District is considered as residential area of high population density. iv) Awali District considered as residential area of low population density (as shown in Fig. 2).



(a) PM Diameters compared with Human Hair Diameter



(b) PM inside Lung



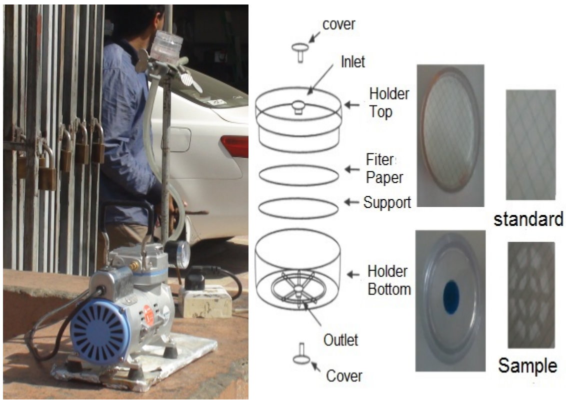
(c) PM inside Alveolus

Fig. 1 Particulate Matter and inhaled path in the lungs

Fig. 2 A map showing sampling locations

B. Sampling Method

The study monitored the concentrations of respirable particulate (PM_{10}, less than 10 microns) using a device all the dust pectoral low volume LVS (Low Volume Sampler) and manufactured by the German Beco (Beco R300) and after calibration device and the use of filters nitrate cellulose size of 0.45 microns for dust least 10 micrometers (Fig. 3). Samples were collected weekly during the period from 1 Ramadan 1434 AH - 27 Safar 1435 AH, collecting a total of 30 samples. The sampling time was 24 h, yielding sample air volumes about 2.9 m^3.



(a) Low Volume Sampler (b) PM_{10} holder

(c) Sampling location at Shebikah

Fig. 3 Low Volume Sampler and PM_{10} holder

Filtration method was used for estimating the total concentration of PM_{10}. Where filter paper is weighted in the laboratory before sampling, and then transported carefully to sampling holder. After sampling the loaded filter is carefully transfer to the laboratory, where it is weighed to constant weight. The difference in weight before and after sampling is equal to weight of PM_{10} collected. PM_{10} concentrations can be calculating by using the sample air volumes and the weight of PM_{10} collected and expressed as µg/m^3 [15].

C. Risk Assessment of PM_{10}

The inhalation dose would be calculated to PM_{10} collected in Makkah during the period from 1 Ramadan 1434 AH - 27 Safar 1435 AH, by using (1) [16].

$$I = (C * DPR * A * EF * ED * 1e\text{-}6) / AT \quad (1)$$

where; I: Inhalation dose (mg/kg/day) (From (1)), C: The concentration of PM10 (µg/m3) (PM10 concentrations), BDR: Daily breathing rate (L/kg/day) (393 L/kg/day), A: Inhalation absorption factor (Equal to 1), EF: Exposure rate (day/year) (365 day/year), ED: Exposure duration (years) (70 years), 1e 6: Inhalation coefficient (0.000001), AT: The average exposure period (day) (25550 Day).

Also, lung cancer risk as a result of exposure to PM_{10} inhalation dose would be calculated by using (2) [16].

$$ICR = (I * CPF) \quad (2)$$

where; I: Inhalation dose (mg/kg/day) (From (1)), CPF: Cancer power factor (1.098).

D. 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 [17], 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) [18].
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.
4) Calculate Relative Risk (RR) manually using (3) [13].

$$RR = \exp [B(X\text{-}Xo)] \quad (3)$$

where; B = 0.0006 - 0.0010 (mean 0.0008), X = Annual mean PM_{10} concentration (μg/m^3), Xo = Baseline (Threshold) concentration (μg/m^3).

5) In (3), high and the mean value of constant B were used to estimate low, high and mean relative risk. Furthermore, instead of baseline concentration, Daily air quality standard of PME for PM_{10} was used, which is 340 μg/m^3 [19]. 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) [20], relative risk (mean, lower and upper) from previous equation, and scientific certainty of relative risk.

E. 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.

III. Results and Discussion

A. PM_{10}

Fig. 4 shows that Respirable particulate matter concentrations compared with Presidency of Meteorology and Environment (PME) Daily standard. It reported that the mean concentrations of PM_{10} were 254.6 (186.1 - 343.2) μg/m^3 in Shebikah, 184.9 (145.6 - 271.4) μg/m^3 in Masfalah, 162.4 (92.4 - 253.8) μg/m^3 in Aziziyah, and 56.0 (44.5 - 119.8) μg/m^3 in Awali. These values did not exceed the permissible limits in PME (340 μg/m^3 as daily average) [19].

These PM_{10} concentrations in Shebikah may be attributed to Expansive of Al-Haram Al-Sharif, especially in the areas of east and North arenas which contain construction activities, traffic of trucks and heavy equipment. In Masfalah, PM_{10} concentrations may be attributed to high traffic density. In Aziziyah, PM_{10} concentrations may be attributed to high density of population, human activities, and construction activities. While in Awali, low PM_{10} concentrations may be attributed to low population density.

Table I shows a comparison between PM_{10} concentrations from the current study and PM_{10} concentrations in different cities around the world countries where were low than that found in Nanjing (682.0 μg/m^3) and Beijing (506.9 μg/m^3) in China [21].

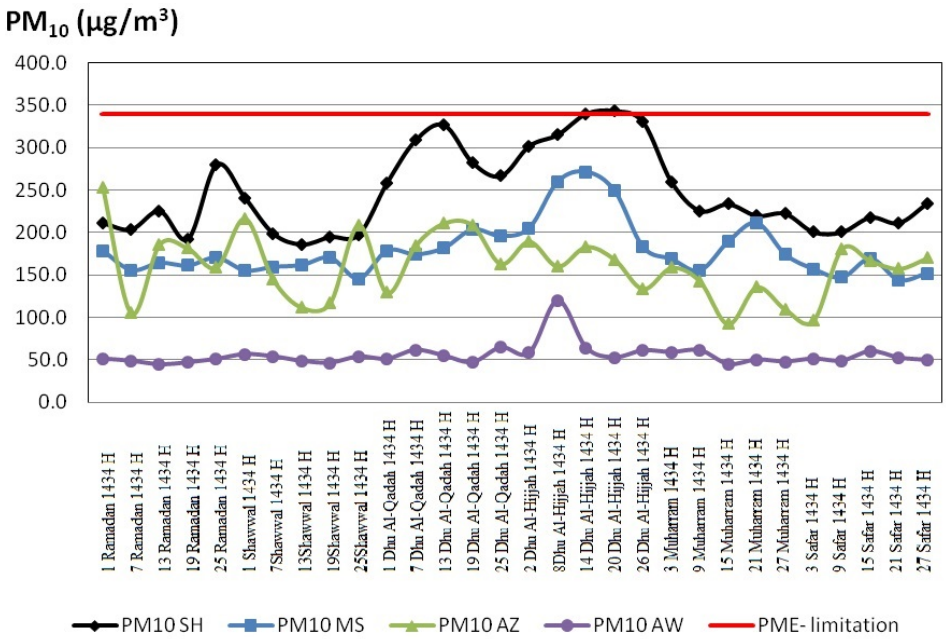


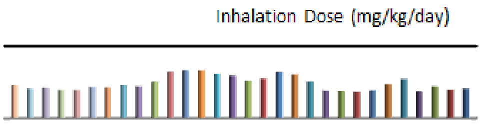
Fig. 4 PM_{10} concentrations at four locations in Makkah city (μg/m^3) during the period from 1 Ramadan, 1434 AH - 27 Safar 1435 AH

TABLE I
PM_{10} CONCENTRATIONS COMPARED WITH DIFFERENT CITIES AROUND THE WORLD COUNTRIES [17], [21]

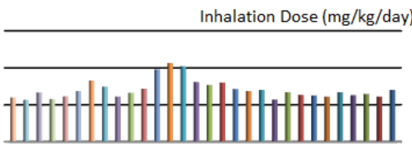
Country			PM_{10} ($\mu g/m^3$)
Saudi Arabia	The current study	Shebikah	186.1 - 343.2
		Masfalah	145.6 - 271.4
		Aziziyah	92.4 - 253.8
		Awali	44.5 - 119.8
	Makkah		145.4
China	Nanjing		682.0
	Beijing		506.9
India	Ahmedabad		171.0
Taiwan	Chaouco		115.0
Turkey	Mersin		26.7
Switzerland	Bern		40.2
Italy	Monte Simon		16.0
Greece	Athens		44.1
Brazil	Rio Djgniero		34.4
	San Polo		38.0
Tanzania	Dar es Salaam		69.0

B. Risk Assessment of PM_{10}

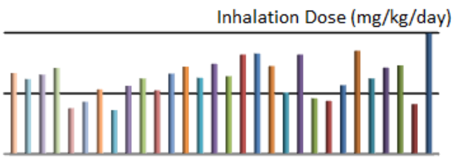
Fig. 5 showed that the inhalation dose of exposure to PM_{10} concentrations during the period from 1 Ramadan 1434 AH-27 Safar 1435 AH. Where, inhalation doses were 0.097 (0.073 -0.135 mg/kg/day) in Shebikah, 0.071 (0.057-0.107 mg/kg/day) in Masfalah, 0.063 (0.036 -0.100 mg/kg/day) in Aziziyah, and 0.22 (0.017- 0.047 mg/kg/day) in Awali. This is due to high density of pilgrims and buses that take them from the hotel to Al-Haram al-Sharif and the holy sites and return them again. Also, Fig. 5 shows that low inhalation dose in Awali location during sampling period, except during 8 and 9 Zu-Elhijjah, this due to a significant increase of the movement of pilgrims and buses bound for Arafat to perform Hajj.



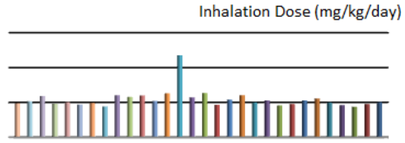
(a) Shebikah Distinct



(b) Masfalah Distinct



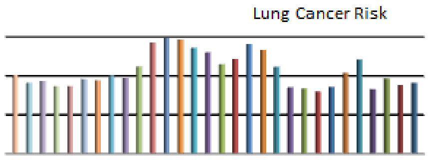
(c) Aziziyah Distinct



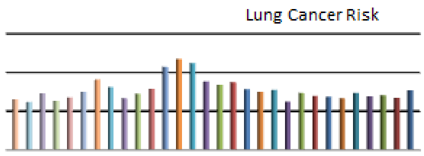
(d) Awali Distinct

Fig. 5 Inhalation Dose of PM_{10} concentration (mg/kg/day) during the period from 1 Ramadan, 1434 AH - 27 Safar 1435 AH

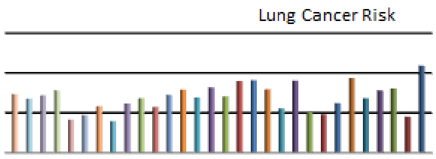
Fig. 6 shows that lung cancer risk as a result of exposure to PM10 inhalation during the period from 1 Ramadan, 1434 AH - 27 Safar 1435 AH. It were 0.11 (0.08 - 0.15) in Shebikah, 0.08 (0.06-0.12) in Masfalah, 0.07 (0.04-0.11) in Aziziyah, and 0.02 (0.02-0.05) in Awali. This is due to high density of pilgrims and buses that take them from the hotel to Al-Haram al-Sharif and the holy sites and return them again. Also, Fig. 5 shows that low inhalation dose in Awali location during sampling period, except during 8 and 9 Zu-Elhijjah, this due to a significant increase of the movement of pilgrims and buses bound for Arafat to perform Hajj.



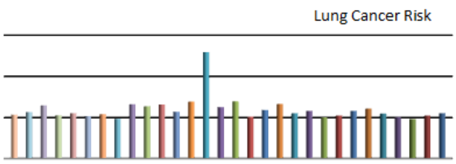
(a) Shebikah Distinct



(b) Masfalah Distinct



(c) Aziziyah Distinct



(d) Awali Distinct

Fig. 6 Lung cancer risk as a result of exposure to PM_{10} inhalation during the period from 1 Ramadan, 1434 AH - 27 Safar 1435 AH

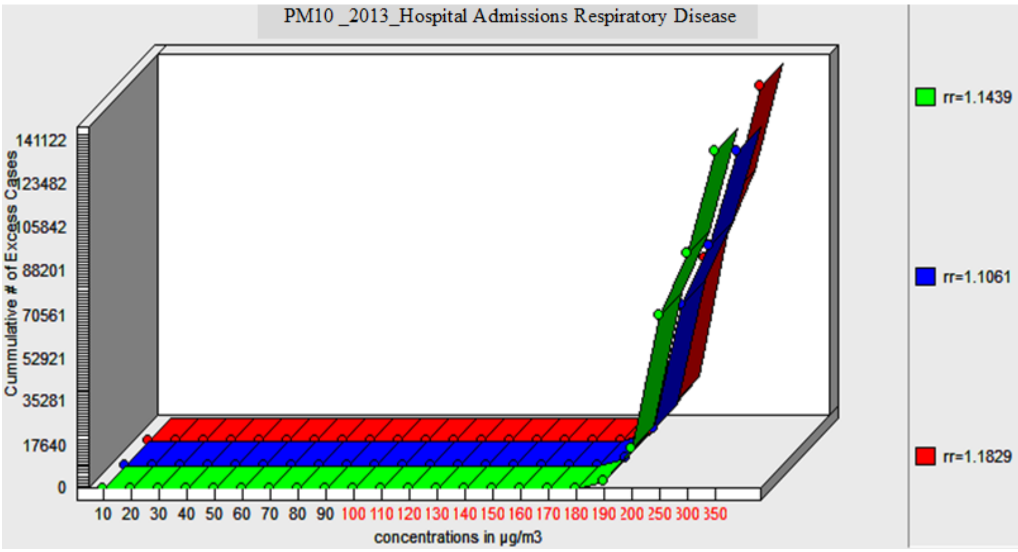
C. AirQ2.2.3 Model

Results AirQ2.2.3 model predicted that the number of hospital admissions due to respiratory diseases as a result of exposure to concentrations of PM10 measured in the current study, to be the number of hospital admissions due to system diseases Respiratory in every 100,000 people were (361-3050 case) in Shebikah, (177-2298 case) in Masfalah, (72-1982 case) in Aziziyah, and (18-70 case) in Awali (as shown in Fig. 7).

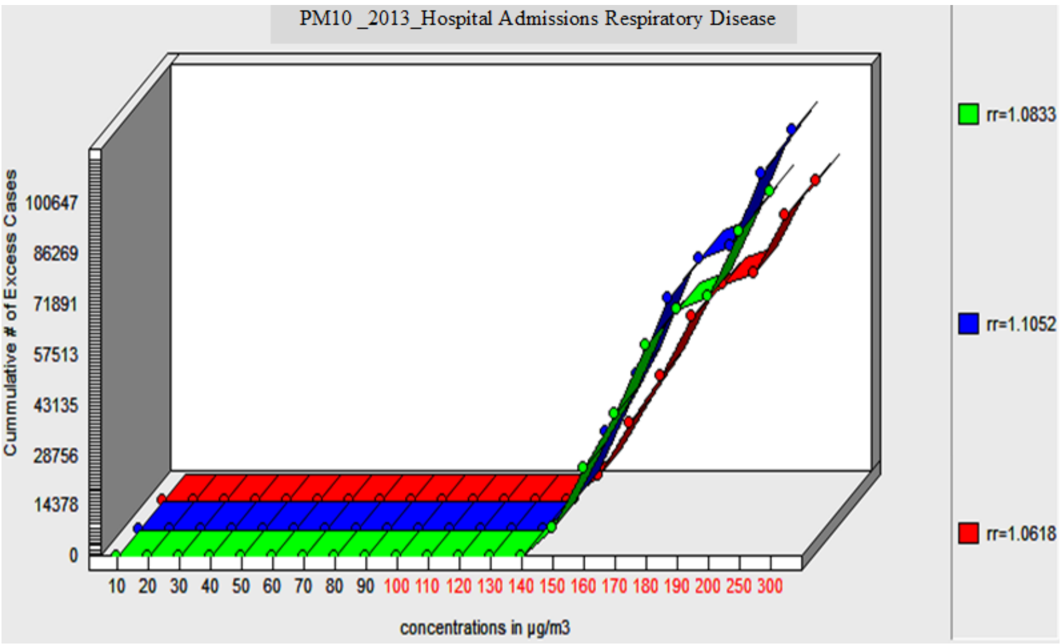
AirQ2.2.3 model results also shows that the response concentration factor (95% CI) was 0.53 (0.11-0.95%), 0.70 (0.33-1.06%), 0.68 (0.37-0.99%), 0.05 (0.06-0.04%) in Shebikah, Masfalah, Aziziyah, and Awali, respectively, per 10 µg/m3 increase. These values were lower than that observed in Cairo, Egypt 4.1 (4-4.2) and in Tallinn - Estonia 1.14% (0.62-1.67), while it is higher than that observed in Shanghai, China 0.23 (0.03-0.48), in north China 0.036 (0.06 - 0.012) [22]-[26].

Comparing the results of the current study 1534 (18-3050 case) in every 100,000 people in all locations with that recorded in different countries around the world, it were less than that recorded in the United States (8970 cases per 100,000 people), in Malaysia (2003 in the case of every 100,000 people). But it was higher than that has been recorded in China (1240 in the case of every 100,000 people) [22], [27]-[32].

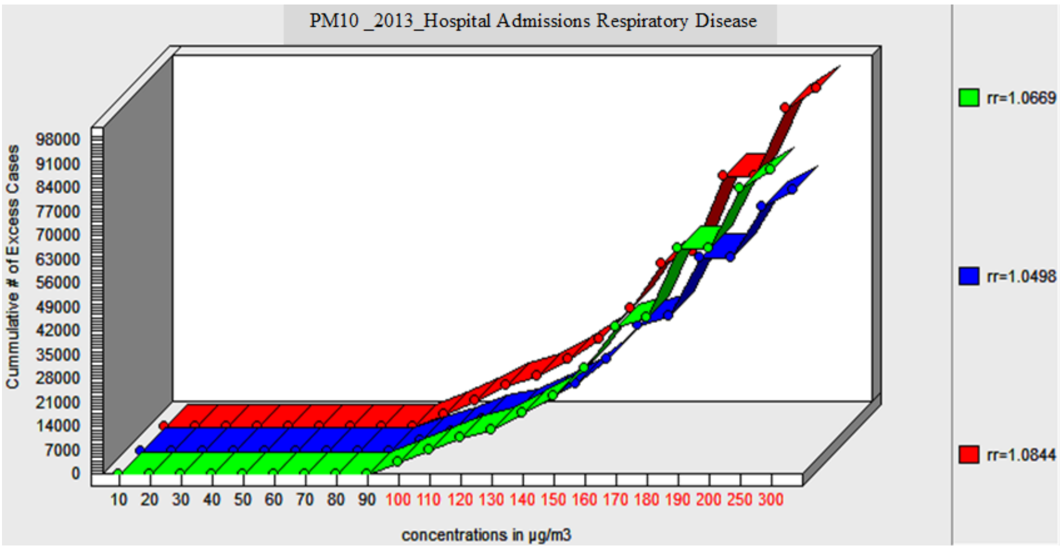
Finally, Studies on inhaled PM_{10} and their relationship to the number of hospital admissions due to respiratory diseases need more time and study to verify that they are the main cause of respiratory diseases in Makkah.



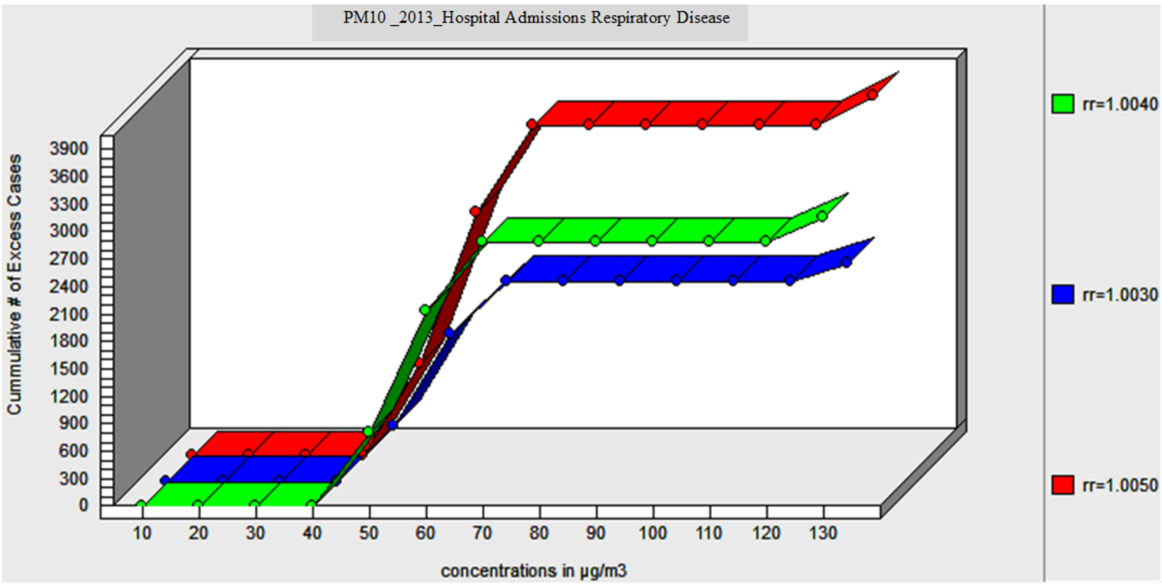
(a) Shebikah Distinct



(b) Masfalah Distinct



(c) Aziziyah Distinct



(d) Awali Distinct

Fig. 7 The number of hospital admissions due to respiratory diseases per 100,000 people

IV. Conclusions

The current study discussed PM_{10} concentrations in in four locations with different activity in Makkah city, Saudi Arabia during the period from 1 Ramadan for the year 1434 AH - 27 Safar 1435 AH. It showed that levels were lower than PME standard (340 µg/m^3 as daily). The PM_{10} concentrations may be attributed to high traffic density, high density of population, and construction activities. While in Awali, low PM_{10} concentrations may be attributed to low population density.

Results showed that the inhalation dose and lung cancer risk as a result of exposure to PM_{10} concentrations during sampling period may be attributed to high density of pilgrims and buses that take them from the hotel to Al-Haram al-Sharif and the holy sites and return them again. While it lower in Awali location during sampling period, except during 8 and 9 Dhul-Hijjah, due to a significant increase of the movement of pilgrims and buses bound for Arafat to perform Hajj.

Finally, Results of AirQ2.2.3 model predicted that the number of hospital admissions due to respiratory diseases as a result of exposure to concentrations of PM_{10} measured in the current study, to be the number of hospital admissions due to system diseases Respiratory in every 100,000 people were 1534 (18-3050 case) in every 100,000 people in all locations, which lower than that recorded in the United States (8970 cases per 100,000 people), in Malaysia (2003 in the case of every 100,000 people) but higher than has been recorded in China (1240 in the case of every 100,000 people). In addition, it shows that the response concentration factor (95% CI) was 0.53 (0.11-0.95%), 0.70 (0.33-1.06%), 0.68 (0.37-0.99%), 0.05 (0.06-0.04%) in Shebikah, Masfalah, Aziziyah, and

Awali, respectively, per 10 μg/m3 increase. These values were lower than that observed in Cairo, Egypt 4.1 (4 - 4.2) and in Tallinn - Estonia 1.14% (0.62-1.67), while it is higher than that observed in Shanghai, China 0.23 (0.03-0.48), in north China 0.036 (0.06 - 0.012).

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