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Particulates in the Atmosphere of Makkah and Mina Valley During Ramadan and Hajj Seasons of 1424 and 1425 H (2004 – 2005)

الأتربة العالقة في أجواء مكة المكرمة ووادي منى خلال موسمي رمضان والحج لعامي 1424-1425 هـ (2004 – 2005 م)

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Abstract: This work has been devoted to study TSP, PM_{10} and $PM_{2.5}$ in the atmosphere of Makkah and Mina valley during Ramadan and Hajj periods, 1424 and 1425 H. On the occasion of Hajj, about 2.5 million persons gather in Makkah and move to Mina valley (4 km^2), 7 km outside east of Makkah. Pilgrims spend 3 nights in the valley. Congested traffic and the high rates of emissions in such a valley of small area coupled with severe weather conditions, make the area ideal for the accumulation of air pollutants. The present investigation shows that the diurnal cycle of PM_{10} in air coincides with the pattern of traffic movements. Particulate matters (PM_{10}) daily concentrations in the atmosphere of Mina valley ranged between 191 - 262 $\mu g/m^3$ during the presence of pilgrims in Mina compared to the European standard of 50μg/m3. These concentrations represent 34% - 40% of TSP. Moreover, TSP concentrations reached 665 $\mu g/m^3$ in Makkah atmosphere during the last ten days of Ramadan compared to the Saudi standard of 340 $\mu g/m^3$. Chemical analysis of PM_{10} indicated high levels of sulphates, ammonium, nitrates and chlorides. For example, the concentrations of nitrates and sulphates of PM_{10} were about 4.9% and 6.1% respectively, compared to 2.1% of nitrates and 2.7% of sulphates in TSP. Health dangers that might be encountered by pilgrims due to these pollutants were estimated. It is recommended to set a well planned air quality management program to protect the air of Makkah

Keywords: *Particulates (PM_{10}, $PM_{2.5}$), pilgrims, transportation, Makkah, Mina, Saudi Arabia.*

المستخلص: اهتمت هذه الدراسة بتقييم مستوي الأتربة الكلية (TSP) والصدرية (PM_{10}) والحويصلية ($PM_{2.5}$) العالقة بأجواء مكة المكرمة ووادي مني خلال موسمي رمضان والحج للعامين 1424 - 1425هـ حيث يجتمع أكثر من 2.5 مليون حاج في مكة خلال موسم الحج، وينتقلون بعدها الي مشعر مني التي تبلغ مساحتها حوالي 4كم^2 وتبعد عن مكة 7 كم شرقا، حيث يبيتون فيها ثلاث ليال وينتج عن ذلك حركة مرورية كثيفة وزحام شديد يسبب ضغطا علي البيئة الهوائية وتراكما للملوثات الهواء الغازية والصلبة المنبعثة من عوادم السيارات والحافلات والتي تزداد في ظل عناصر المناخ السائدة بمكة. تم جمع العينات اليومية للغبار طبقا لأحجامها باستخدام أجهزة جمع الأتربة العالقة الكلية والجسيمات الأقل من 10 ميكرو متر والاتربة الأقل من 2.5 ميكرو متر وتم تحليلها كيميائيا. تراوحت التركيزات اليومية للأتربة الصدرية العالقة في وادي مني بين 191 – 262 ميكرو جرام/م^3 طيلة فترة اقامة الحجاج بمشعر مني وهذا يمثل قرابة 34 % - 40 % من مجموع الأتربة الكلية العالقة. كما وصلت تركيزات الأتربة الصدرية والعالقة الكلية بجوار الحرم المكي الشريف الي أكثر من 250 ميكروجرام/ م^3 و665 ميكروجرام / م^3، علي التوالي مقارنة بالحد الاقصي المسموح به بالمملكة العربية

السعودية وهو 340 ميكروجرام /م^3. كذلك أظهرت التحاليل المخبرية وجود تركيزات عالية لكل من الامونيوم والنترات والكبريتات في الأتربة الصدرية مقارنة بتلك التي رصدت في الأتربة الكلية العالقة، فعلى سبيل المثال كانت بلغت النترات والكبريتات بالأتربة الصدرية قرابة 4.9 % و6.1 % علي التوالي مقارنة بـ 2.1 % نترات و2.7 % كبريتات بالأتربة الكلية العالقة. وأجريت محاولة لتقدير المخاطر الصحية التي من الممكن ان يتعرض لها الحجاج نتيجة للتعرض لهذه الملوثات، وأوصت الدراسة بضرورة خفض تركيزات هذه الأتربة العالقة والملوثات من خلال برنامج متكامل للإدارة البيئية السليمة.

كلمات مدخلية : *الأتربة الكلية العالقة (الأتربة الصدرية (PM_{10}) والأتربة الحويصلية ($PM_{2.5}$))، الحجاج، النقل، مكة، منى، المملكة العربية السعودية.*

INTRODUCTION

Makkah, Saudi Arabia is the holy city for Muslims. Mina valley lies just outside Makkah, 7 km to the east of the city centre and the holy mosque (Al-Masjid Al-Haram). Towards the Muslim pilgrimage period every year, Muslims start to gather in Makkah on the beginning of Zulhijah (the last month of the Muslims calendar year). Pilgrims (more than 2.5millons) move on the 8th of Zulhijah to Mina Valley. They stay in the valley for one night before they proceed to Arafat (about 12 km to the south) on the morning of 9th of Zulhijah, "Day of Al-Wakffah".

On the early morning of 10th of Zulhijah, all pilgrims return to Mina on their way back to Makkah. This time they spend 3 days "Tashreek days" and sleep in tents at Mina which has an area of 4 km^2, and each pilgrim has less than 2 m^2 to live on. Sources of air pollution are mainly fuel combustion with reference to auto exhaust and the movements on the bottom of the valley and the surrounding mountains. Means of transportation are mainly automobiles.

The central area of Makkah is characterized by a very highly dense population, high buildings, narrow streets, and congested traffic flow. Congestion and high rates of pollutant emissions in such valleys of small areas coupled with predominant weather condition of high temperature, lack of rainfall, prevailing one wind direction, low wind speeds and the potentiality of thermal inversions make the area an ideal situation for the accumulation of air pollutants. The problem is of concern when scavenging mechanisms fail to dilute pollutants, pilgrims may face an acute health problem (Nasralla, 1986).

The present work is the first outcome of a research project conducted to investigate air quality with respect to particulate matters and the factors affecting pollutant concentrations during the gathering of this sort of crowdedness, as well as to learn about the required plans for air quality management under such conditions. This is the only occasion of its kind in a limited area under subtropical conditions and has typical topographical features for pollutant accumulation. Therefore, the present work is of a wide interest for air pollution studies.

METHODOLOGY

Air pollution monitoring program was conducted in Makkah and Mina valley to monitor air pollutants (CO, SO_2, NO_x, O_3 and particulates) and weather elements during pilgrimage periods of 1424 and 1425H (2004 and 2005G). Particulate matters were also measured in Makkah during the month of Ramadan (October 2004). Total suspended particulates, PM_{10} and $PM_{2.5}$ were sampled using high volume samplers, PM_{10} sampler and $PM_{2.5}$ sampler (Staplex Co.) respectively during pilgrimage period in Mina valley. Measurements were carried out at two levels. The first level is 4 m above the ground surface and the second level is 1.6 m at the entrance of one of the pilgrims' tents. Sampling period started during both years of the study on 5th to 15th of Zulhijah in 1424 and 1425H (27th Jan. – 6th Feb. 2004, and 14th – 25th Jan. 2005).

Total suspended particulates were sampled in three locations at Makkah city. These sites are (a) the central area adjacent to the holy mosque, (b) city centre about 1km distance from the holy mosque and (c) Alazizia residential district at a distance of 6 km west of the central area of Makkah and about 2 km east of Mina valley. PM10 was also continuously monitored at the central area of Makkah adjacent to the holy mosque using ambient particulate monitor (beta

ray absorption). TSP, PM_{10} and $PM_{2.5}$ were sampled on quartz filters during pilgrimage period in Mina Valley. TSP in Makkah locations were sampled using glass fiber filters. Ions in half of each sample were extracted using deionised water and analysed for chlorides (titrimetry), ammonium and nitrates (colouremetry) and sulphates (turbidimetry) according to the methods described by Nasralla (1983).

The second part of the samples were digested using nitric and hydrochloric acids(Nasralla, 1999 and Harrison and Perry, 1986) and analysed for heavy metals using atomic absorption spectrophotometer, Perkin Elmer, Analyst 300. Particulate samplers were periodically calibrated using air flow calibration kit. Quality assurance/Quality control program for chemical analysis include the extraction of clean filter using deionised water. This extraction was used as a blank and solutions of known concentrations of analysed ions were used for standardization of the analysis procedures

RESULTS AND DISCUSSIONS

Figure (1) shows the recorded TSP concentrations in the atmosphere of the three monitored locations in Makkah during the month of Ramadan 1424H (Oct/ Nov 2004). About 2 million persons visited Makkah to pray in the holy mosque during nights of Ramadan. They spent 1-4 nights in the city.The number of the visitors increased gradually reaching its peak during the last 10 days that is the days between 20th and 27th of Ramadan. The movements of the visitors and their vehicles in the central area of Makkah have been reflected on the concentrations of particulates in the city air. This is very clear from the differences between the TSP concentrations recorded in the atmosphere of the three sites of measurements and the significant increase of TSP during the last 10 days as compared to those found on the beginning of the month (Figure 1). Here, it should be noted that TSP reached a concentration of 665 $\mu g/m^3$ during the 20th of Ramadan including the night of the 21st.This concentration is much higher than the Saudi Air Quality Standard of 340 $\mu g/m^3$. Figure (1) also indicats that TSP in the atmosphere of the residential area, 6 km out of the city centre, was only 25% higher than the daily limit of 120 $\mu g/m^3$, previously recommended by WHO (1987).

Daily average concentrations of TSP in the air of the central area of Makkah reached levels as much as twice of that previously recommended limit of WHO (1987). Moreover, TSP concentrations in the central area during the peak time of the days 20th - 27th of Ramadan reached three times more than those found in the air of the residential area and reaching about 5 times of that previously recommended by WHO (1987). Here, it should be noted that WHO removed their guideline for particulate matters from recent publications (WHO, 2005; 2006) and stated that there is no safe limit can be recommended for particulates above 20 $\mu g/m^3$. These high levels of TSP extended to cover the surrounding air of Makkah city centre (Figure 1). Moreover, the daily average concentrations of PM_{10}, during the last 10 days of the month, reached levels of more than 250 $\mu g /m^3$ with a maximum value of 800 $\mu g /m^3$ at midnight of 21st of the month. In the absence of Saudi standard for PM_{10}, these concentrations may be compared to the European standard of 50 $\mu g /m^3$.

The results of particulates monitoring program during pilgrimage period show clearly the impact of transportation and the movements of pilgrims on the variations in concentrations of particulate in the atmospheres of Makkah and Mina valley. Results indicated three different trends of daily variations in TSP concentrations in the air of the three sites of measurements as shown in Figure (2). It may be seen that the lowest concentrations at the three locations were recorded on 9th of Zulhijah in 1424H (31st Jan., 2004). On that day all pilgrims moved to Arafat valley, 19 km to the SE of Makkah and 12 km of Mina valley. Here, it should be noted that the high levels of TSP reflected the movements of the pilgrims with their vehicles in Makkah, Mina and back to stay in Makkah. In other words, the highest levels of particulates were recorded in the places they live at or move to. Figure 2 also shows that TSP concentrations increased

to levels of > 200% during their residence in Mina and >300% during their stay in Makkah as compared to concentrations recorded on 9th of Zulhijah when they moved to Arafat valley. Here, it should be noted that the early morning movements of vehicles in Makkah and Mina on the 9th of Zulhijah resulted in TSP concentrations twice that recorded in the residential area of Alazizia on the same day. This furthermore confirms the contribution of transportation in polluting the air of Makkah and Mina with particulate matters. Results of the present work show that PM_{10} concentrations in Mina valley followed the same pattern with regard to TSP daily variation during the period of pilgrims' occupancy of the valley. The recorded PM10 concentration in the atmosphere of the valley on 9th of Zulhijah in 1424H (31st Jan. 2004) was less than 50 $\mu g/m^3$ and peaked to 137 $\mu g/m^3$ on the return of pilgrims back to Mina on 10th of Zulhijah (1st Feb. 2004).

Furthermore, Figure (3) shows the concentrations of TSP, PM_{10} and PM2.5 in Mina valley during the pilgrimage period of 1425H (January 2005). This figure clearly confirms the influence of the vehicles and movements of pilgrims on the concentrations of particulates in the air of the valley. PM_{10} daily concentrations in the atmosphere of Mina valley ranged between 191 - 262 $\mu g/m^3$ during the pilgrims' occupancy of Mina. These concentrations represent 34% - 40% of TSP. This percentage of PM_{10} is similar to that found in several urban areas such as Cairo (Nasralla, 1997; Nasralla, *et al.* 2006), Athens (Chaloulakou, *et al.* 2005), China (Ying, 2006) and several other cities of the world (WHO, 2006; 2000a). Furthermore, high levels of $PM_{2.5}$ have been recorded in the atmosphere of the valley representing 34% - 42% of the recorded PM_{10} concentrations. One of the interesting findings of this work is that the levels of $PM_{2.5}$ and PM_{10} at 4.5 m above the ground surface did not vary much than those recorded at 1.6 m at the entrance of one of the pilgrim's tents. Knowing that pilgrims usually sleep in tents as well as outside and around streets, it can be concluded that pilgrims are exposed to high levels of these air pollutants with deleterious effects on their health. Here, it should be noted that WHO (2000) stated that there is no safe limit for the exposure to PM_{10} levels above 20 $\mu g/m^3$.

Similarly, pilgrims were exposed to high levels of PM_{10} during their residence in Makkah close to the central area (Figure 4). These daily concentrations of PM_{10} recorded in the atmosphere of Makkah may be compared to the European United Community (EUC) air quality standard of 50 $\mu g/m^3$. Moreover, it may be seen that the pattern of PM_{10} variation in Makkah air during the different occasions of pilgrimage was very similar during both years (2004 and 2005) of the study (see figure 4). This confirms the reflection of man's activities with reference to transportation on the concentrations of PM_{10} in the air of Makkah central area. This conclusion is furthermore confirmed by the diurnal variation of PM_{10} and CO in Makkah air (Figures 5 and 6). These figures indicated, to a great extent, similar diurnal cycles for both air pollutants. Furthermore, the increase of PM_{10} concentrations in Makkah air during night time is very similar to that recorded in Mina valley. This can not only be explained by the movements of vehicles 24 hours daily during pilgrimage, but possibly due to the nocturnal formation of a stable and stagnant atmosphere and the long periods of calm or light winds during night times

Analysis of particulate samples collected from Mina atmosphere during "Tashreek days" indicated that PM_{10} contains high levels of nitrates (NO_3^-), sulphates (SO_4^{--}), ammonium (NH_4^+) and chloride (Cl^-) compared to those encountered in TSP (Table 1). The high levels of nitrates, sulphates, ammonium and chloride recorded in PM10 samples are in accordance with previous findings in several European urban areas (Clarke, *et al.* 1999 and WHO, 2000a).

Table 1. Average Concentrations of PM_{10} and TSP Anions in Mina.

Ion	TSP, %	PM_{10}, %	TSP, µg /m³	PM_{10}, µg/m³
NO_3^-	2.1	4.9	7.8	6.3
SO_4^{--}	2.7	6.1	10	7.9
NH_4^+	1.8	3.8	6.7	4.9
Cl^-	1.4	1.9	5.2	2.5

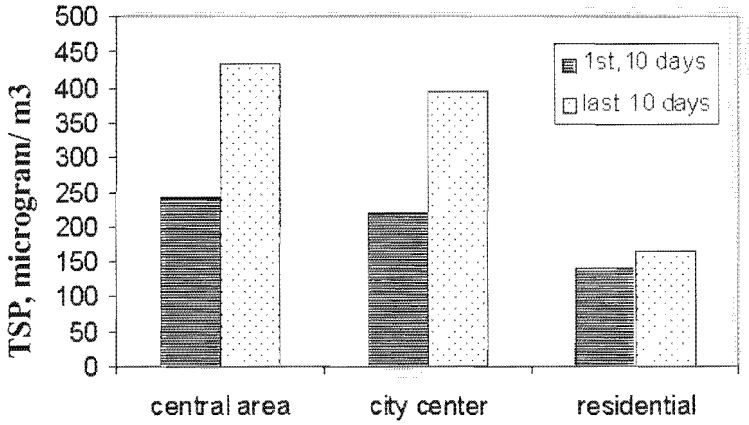

Fig. 1. TSP in Makkah Atmosphere During Ramadan 1424 (Oct/ Nov 2004).

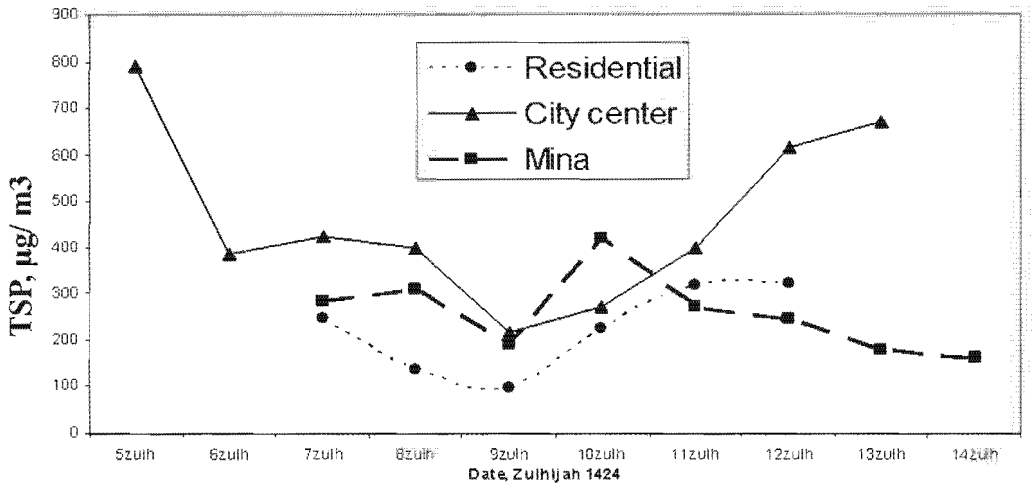

Fig. 2. TSP in Makkah and Mina Atmospheres During Pilgramage Session, Zulhijah 1424H (Jan/ Feb 2004G).

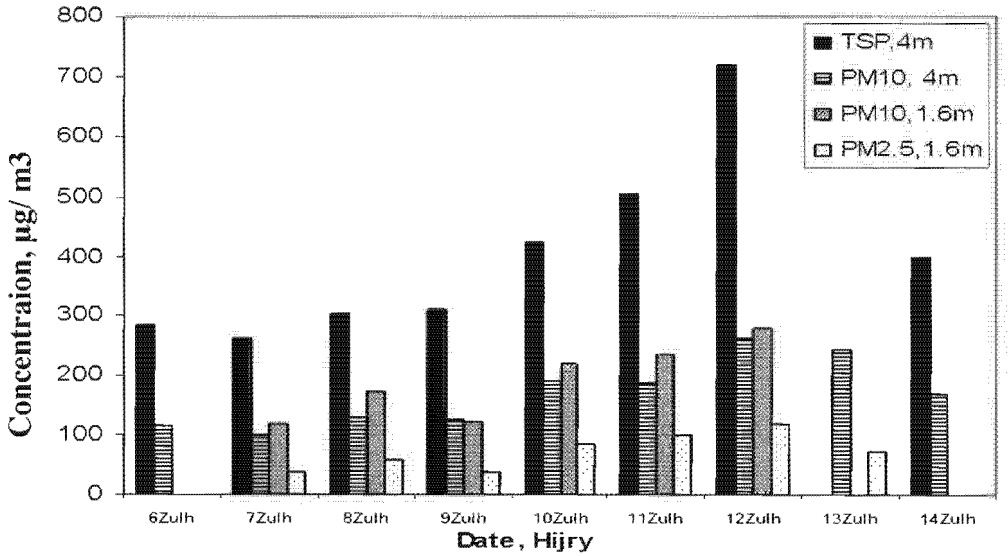

Fig. 3. TSP, PM_{10} and $PM_{2.5}$ in Mina Valley During Pilgramage 1424H, Jan 2005G.

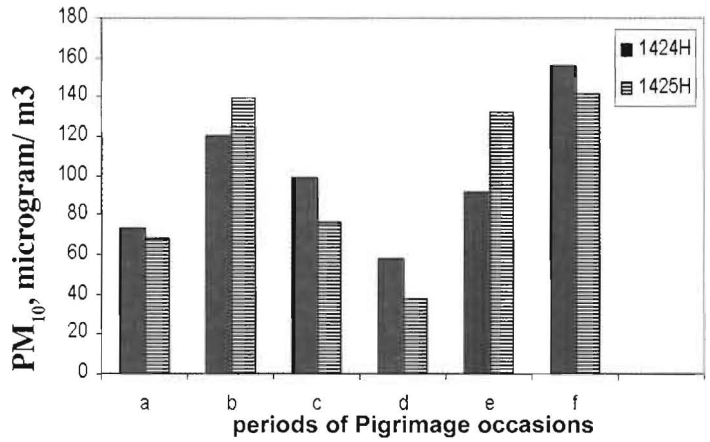

Fig. 4. PM_{10} in Makkah centeral area during Various pilgrimage occasions.

Legend: *a, before pilgrims arrival to Makkah, 24th – 29th of Zulkedda, b, residence in Makkah before pilgrimage, 1st – 6th of Zulhijah, c, leaving to Mina and Arafat, 7th and 8th of Zulhijah, d, Arafat day, 9th of Zulhijah, e, residence in Mina and moving between Mina and Makkah,10th – 12th of Zulhijah, f, back to stay in Makkah, 14th – 20th of Zulhijah*

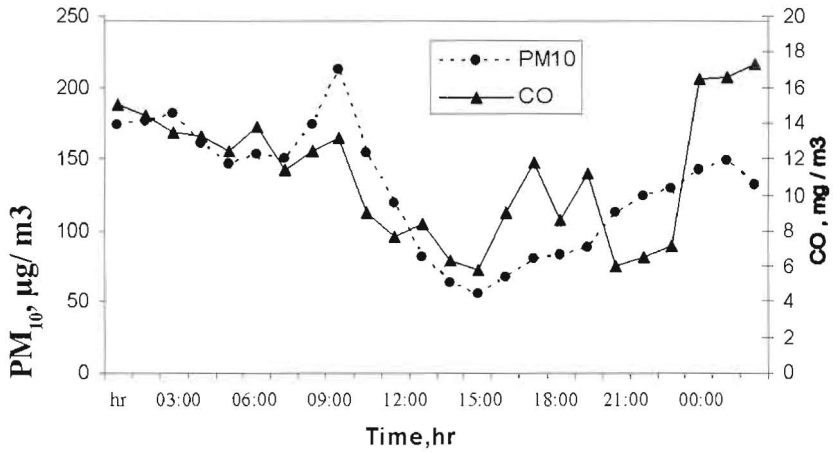

Fig. 5. Diurnal Variation of CO and PM_{10} in Makkah Centeral Area, 4 Zulhijah 1425H (14Jan 2005).

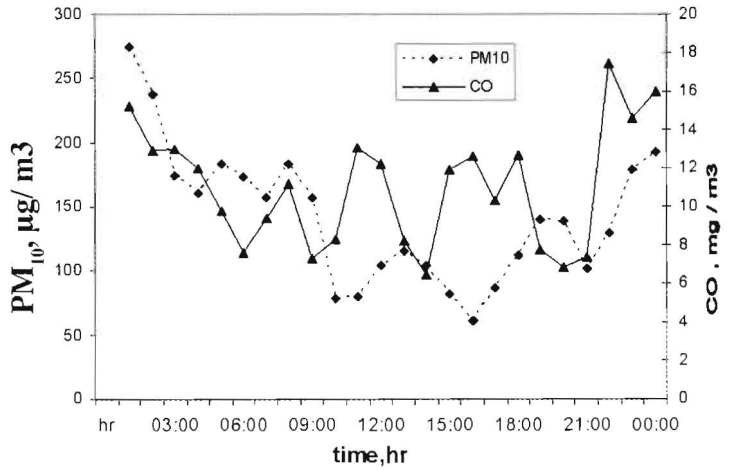

Fig. 6. Diurnal Variation of PM_{10}CO in the Atmosphere of Makkah Centeral Area, 4 Zulhijah 1425H (14Jan 2005).

A trial was made to assess the health risks for pilgrims during their residence in Makkah and Mina due to the exposure to PM_{10}. Calculations were conducted according to equations 1-4 given by (WHO, 2000), (see Table 2).

% increase in daily mortality = (0.07 ± 0.012) x PM_{10}..... (1)

% change in hospitals admission = (0.084 ± 0.033) x PM_{10}..... (2)

% change in cough = (0.455 ± 0.228) x PM_{10} ..... (3)

% change in symptom exacerbation = (0.345 ± 0.162) x PM_{10}..... (4)

Table 2. Estimated Risks for Pilgrims Health During Residence in Mina and Makkah, Pilgrimage 1425H (2005).

	% increase in mortality	% change in hospitals admission	% change in cough	% change in symptom exacerbation
Mina	13 - >16	16 - >23	86 - >123	65 - >101
Makkah	8 - 14	10 - 14	51 - 77	39 -59

The high temperature and relative humidity, existence of high concentrations of other air pollutants and the required heavy physical activities and high particulate concentrations are likely to cause adverse health effects during "Tashreek days" in Mina and during their residence in Makkah central district. It is important to keep in mind that more than 350,000 pilgrims were aged over 50 years and more than 75,000 over 65 years of age (Central Department of Statistics & Information, 2005) and are thus more susceptible to the adverse effects of air pollutants on health. It is recommended to conduct thorough investigations and source apportionment studies to evaluate the exact contribution of the different types of vehicles to the problem of PM_{10} in Makkah and Mina. In fact, well planned air quality management and alternative transportation system are urgently recommended for Makkah and holly places.

CONCLUSION

TSP, PM_{10} and $PM_{2.5}$ in the atmosphere of Makkah and Mina valley were measured during Ramadan and Hajj periods. The TSP concentrations in the central area reached about 5 times of that previously recommended by WHO (1987) during the peak time of Ramadan due to the massive transportation movements. The present investigation shows that the diurnal cycle of PM_{10} in air coincides with the pattern of traffic movements. PM_{10} daily concentrations in the atmosphere of Mina valley ranged between 191 - 262 $\mu g/m^3$ during the pilgrims' occupancy of Mina. Analysis of PM_{10} indicated high levels of sulphates, ammonium, nitrates and chlorides as compared to TSP. It was also estimated that these PM_{10} levels may increase the rates of hospital admissions and mortality.

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