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Assessment of PM10, CO and Noise Levels at the Central Area of Makkah During Hajj Season 1429H (2008)

تقييم مستويات الجسيمات الدقيقة وأول أكسيد الكربون والضوضاء في المنطقة المركزية بمكة خلال موسم حج 1429 هـ (2008م)

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Abstract: The present investigation aims to study temporal and spatial variation in the concentrations of PM_{10}, CO and noise levels at the central area (322 m altitude, 21°.25 N, 39°.52 E) in Makkah, Saudi Arabia, during hajj season in 1429H (2008). Measurements of PM_{10}, CO and noise levels were conducted using the High Volume Sampler of PM_{10}, CO gas monitor and the Sound level Meter of model CR812B, respectively. The daily averaged measured PM_{10} concentrations at the central area were high and ranged between 85 – 200 μg/m3. Despite such PM_{10} concentrations are lower than the recorded one (250 $\mu g/m^3$) by previous studies and are within the permissible limits by GERRI (340 $\mu g/m^3$) [*GERRI*, 2006] but they were still exceeding the recommended limits of PM_{10} (20 $\mu g/m^3$) by WHO [*WHO*, 2000]. However, the averaged measured concentrations of CO were less than 20 mg/m^3/hr except Tunnel (1) that reached 97 mg/m^3/hr. The measured LAeq at the central area sites varied between 71 – 98 dB exceeding the recommended value of 70 dB by WHO. This study also discussed the temporal variation of all these pollutants during hajj season and its expected sources in the central area and its health effects on pilgrims. The solutions were suggested to improve the air quality. Most important suggestion is adopting a new public transportation system at this central area in Makkah such as monorail, trams or train networks that would extremely reduce air pollutant concentrations and noise levels. A comprehensive programme is also required for the safety environmental management.
Keywords: *PM_{10}; CO; noise levels; air pollution; central area; Hajj; Makkah.*

المستخلص: القياسات الحالية هدفت لدراسة التغيرات الزمانية والمكانية لتركيزات الجسيمات الدقيقة الأقل من 10 ميكرومترات (PM_{10})، وأول أكسيد الكربون (CO)، ومستويات الضوضاء في المنطقة المركزية (الارتفاع 322 م، 39.52° شرقا – 21.25° شمالا) في مكة المكرمة بالمملكة العربية السعودية خلال موسم حج عام 1429هـ (2008م). ولقد أجريت قياسات الجسيمات الدقيقة وأول أكسيد الكربون ومستويات الضوضاء باستخدام أجهزة جمع الجسيمات الدقيقة الأقل من 10 ميكرومترات، وجهاز رصد غاز أول أكسيد الكربون، وجهاز قياس مستوى الضوضاء موديل CR812B، على التوالي. وقد أوضحت الدراسة ارتفاع معدلات التركيزات اليومية للجسيمات الدقيقة بالمنطقة المركزية والتي تراوحت بين 85 - 200 ميكروجرام/م^3 وعلى الرغم من أن هذه التركيزات أقل من تلك التي سبق رصدها في أحد الدراسات السابقة (250 ميكروجرام/م^3) وتقع ضمن الحدود الآمنة حسب المواصفات السعودية (340 ميكروجرام/م^3) إلا أنها تتجاوز تلك الموصى بها من قبل منظمة الصحة العالمية (20 ميكروجرام/

م3). في حين كان معدل تركيز غاز أول أكسيد الكربون أقل من 20 ملليجرام/م^3 في الساعة في جميع مواقع القياس، عدا نفق رقم (1) والذي وصل فيه التركيز إلى 97 ملليجرام/م^3 في الساعة. ومن جهة أخرى تراوحت مستويات الضوضاء المكافئة في المنطقة المركزية بين 71 - 98 ديسيبلا متجاوزة بذلك القيمة الموصى بها (70 ديسيبل) من قبل منظمة الصحة العالمية. كما تطرقت الدراسة لمناقشة تغير تركيزات جميع هذه الملوثات عبر الأزمنة المختلفة طيلة موسم الحج ومصادرها المحتملة بالمنطقة المركزية وانعكاساتها الصحية على الحجيج واقترحت بعض الحلول لتحسين نوعية الهواء بالمنطقة والتي كان من أهمها ضرورة اعتماد نظام جديد للنقل العام بالمنطقة المركزية في مكة المكرمة مثل النقل المعلق، أو الترام، أو شبكات القطار، والتي من شأنها أن تقلل بشكل كبير تركيزات ملوثات الهواء ومستويات الضوضاء إضافة إلى تنفيذ برنامج متكامل للإدارة البيئية السليمة.

كلمات مدخلية : *الجسيمات الدقيقة، أول أكسيد الكربون، مستويات الضوضاء، تلوث الهواء، المنطقة المركزية، الحج ، مكة.*

INTRODUCTION

Makkah is the Holy Capital City (322 m altitude, 21°.25 N, 39°.52 E) in Saudi Arabia and it is a valley that is surrounded by many mountains from all directions. Makkah is considered as the holiest city on the earth to Muslims. Five times each day, the world's one billion Muslims, wherever they may be, turn to the Holy City of Makkah to pray, and at least once in their lives, all Muslims who are not prevented by personal circumstances perform the Hajj, the pilgrimage to Makkah. Thus each year the Holy City of Makkah hosts more than two millions hajjis (pilgrims) from all over the world. The most important site in Makkah is the Holy Mosque (Almasjed Alharam) that houses the Ka'aba, in the corner of which is set the Black Stone which marks the starting point for the seven circumambulations (Tawaf) of the Holy Mosque. This Holy Mosque is located at the middle of the city centre that is also known as the central area. This central area is about the circle that has a radius of 1.5 km with centre of Ka'aba and its circumference is surrounded by the second ring road in Makkah. Hence it is very close to the Holy Mosque where most of pilgrims prefer to accommodate. This results in increasing overcrowding in this region, as a result of density urban area, rising numbers of attendees of the Holy Mosque (the inhabitants and pilgrims) and increasing the different activities associated with the pilgrimage rite. All these factors constitute a burden on the air quality in the central area and could affect the pilgrims' health. Thus, many studies were published for assessing air quality at the central area in Makkah during Hajj seasons to protect pilgrims from air pollution. For example, the conducted studies by the Institute of the Custodian of the Two Holy Mosques for Hajj Research in Makkah from 2004 to 2009, showed high concentrations of air dust and pollutants at the central area particularly in roads and tunnels leading to the Holy Mosque [*Nasralla*, 2004 - 2008; *Nasralla and Seroji*, 2007, 2008; *Seroji*, 2008]. Air dust studies showed increase of the total suspended particulates (TSP, larger than 10 micrometers), as well as particulates matters of less than 10 micrometers and greater than 2.5 micrometers (PM_{10}) in the air of the central area [*Nasralla*, 2004 - 2008]. They pointed that the averaged concentrations of TSP in the air next to the Holy Mosque increased to approximately 665 μg/m^3 for 24 hours, while the averaged PM_{10} concentrations were more than 250 μg/m^3/24hr. This averaged PM_{10} concentration of 250 μg/m^3 is within the permissible limits (340 μg/m^3/24h) of the General Environmental Regulations and Rules for Implementation (GERRI) in the Kingdom of Saudi Arabia[*GERRI*, 2006]. However, it is far in excess of the recommended limits of PM_{10} (20 μg/m^3) by the World Health Organization [*WHO*, 2000], as it exceeds European Standards of 50 μg/m^3 [*WHO*, 2002]. In terms of other pollutant concentrations, studies showed that the emissions levels from vehicles exhausts of primary pollutants, such as carbon monoxide (CO), nitrogen oxides (NO_x) and sulfur dioxide (SO_2) were responsible for air pollution. In addition, the concentration of ozone sharply increased in summer time [*Nasralla and Seroji*, 2007]. These pollutants may affect pilgrims' health and can cause some respiratory diseases, coronary heart disease and pneumonia [*WHO*, 2002].

Nevertheless, recent study showed that the average concentration of CO was very limited (7 - 13 mg/m^3 for 15 minutes) in the halls of the Holy Mosque near the ventilation halls of Assog Assageer tunnel [*Seroji*, 2011]. In addition, the noise studies at the central area in Makkah were performed by some researchers showing that the

high levels of noise were ranging between 80 - 95 dB [*Saati and Shaheen*, 2000; *Seroji*, 2011; *Shehatah*, 2003], while another study indicated that the equivalent noise levels of LAeq in the pedestrian tunnels that connect the Holy Mosque and Mina Valley, reached about 100 dB [*Balila and Siddiqi*, 1994]. The noise levels were also measured at three big Halls of the Holy Mosque in Makkah during Ramadan and ranged between 74 – 84 dB [*Seroji*, 2011]. The high noise value of 95 dB is surpassing the recommended limits of 55 dB by WHO [*WHO*, 1999]. These high levels of noise may cause serious health damage to the sense of hearing and nervous system and circulatory system and digestive system [*WHO*, 1999]. Hence, the central area ambient in Makkah is very critical and important for pilgrims' health every year.

The aim of this study is to assess the concentrations of both PM_{10} and CO, as well as the LAeq in streets and tunnels at the central area in Makkah during hajj season in 2008 (1429H). Such measurements of these factors were compared to that out of the central area.

METHODS AND MATERIALS

The PM_{10} concentration was collected every 24 hours daily by High Volume Sampler of PM_{10} that made by Staplex Air Sampler Division in USA. Such instrument was calibrated using the High Volume Calibration Kit of model CKHV810 with Air Sampler equipped with 8"×10" Filter Holder Assembly and includes a Calibration Orifice prescribed for use by U.S. Environmental Protection Agency, a water manometer, a series of resistance plates and a carry case. After calibration the device was launched with filters quartz for collecting dust less than 10 micrometers in diameter. Concentration of CO was measured using CO gas monitor that is manufactured by German company of Draeger. CO monitor was calibrated via using CO gas cylinder after adjusting the zero calibration function. The concentration of CO was sampled every 15 minutes and then averaged every hour. In term of noise measurements, the LAeq, Lmax and Peak functions were detected using an integrated Average Sound Level Meters, models numbers of CR: 812B that is developed by the Cirrus research PLC, in UK. The LAeq is referred to a standard weighting of the audible frequencies designed to reflect the response of the human ear to noise during a period of time. The LAeq were sampled every 15 minutes. In addition, the function of Lmax is referred to the maximum sound level with 'A' frequency weighting and with fast time weighting. However, the Peak function is referred to the maximum value reached by the sound pressure at any instant during the measurement period of time in dB unit.

Measurements were sampled daily for 24 hours from 00:00 to 24:00 in term of PM_{10} and every 8 hours in term of both CO and LAeq from 16:00 to 24:00 during the beginning of Zulhijah month (Hajj month) between 2 - 10 /12/1429H (30/11 – 8/12/2008). During these ten days of Zulhijah all pilgrims are gathering in Makkah and spending the first 7 days of Zulhijah in Makkah city and particularly in the central area, while on 8th of Zulhijah they move to Mina Valley to stay there and sleep in the valley for one night before they proceed to Arafat (about 12 km to the south east of Makkah) on the morning of 9th of Zulhijah, "Day of Al-Wakffah". On the early morning of 10th of Zulhijah, all pilgrims return to Mina and then pilgrims return to Makkah to perform Tawaf Alefadah in the Holy Mosque. At night on 10th of Zulhijah pilgrims move to Mina Valley to spend 3 days "Tashreek days" in their camps.

There were 7 sites of measurement in Makkah; five of them were inside the central area (Alshobikah, Ajiad Assod, Alghazah, Umm Alqura Street and Assouk Assagheer tunnel (Tunnel_1)) while, the other two were outside of the central area (Alaziziah and Mahbas Aljin tunnel (Tunnel_2)). These sites are selected depending on the geographic directions, where Alshobikah from the North, Ajiad Assod and Tunnel_1 from the South, Alghazah from the East and Umm Alqura street from the west. However, in terms of outside of the central area, Alaziziah area was in the South East and it was located between Mina and Makkah. Tunnel_2 was located in the East. Data were collected and analysed for assessment of air quality and noise levels inside and outside of the central area.

RESULTS AND DISCUSSIONS

PM_{10} concentrations

Temporal and spatial variations of PM_{10}

levels were presented daily in Figure 1 at four sites of Ajiad Assod, Alshobikah, Alghazah and Alaziziah from 3rd to 10th of Zulhijah. It was impossible to launch the High Volume Sampler of PM_{10} in Umm Alqura Street and tunnels, where there was not any source for electricity. However, most sites were covered here for several days (see Figure 1). It is clear that the PM_{10} concentrations in all sites were high and ranging between 85 – 200 $\mu g/m^3$. These values are within the permissible limits by GERRI (340 $\mu g/m^3$) [*GERRI*, 2006] but they were still exceeding the recommended limits of PM_{10} (20 $\mu g/m^3$) by WHO [*WHO*, 2000] and by European Standards of 50 $\mu g/m^3$ [*WHO*, 2002]. In the central area sites Alghazah area has shown the highest concentrations between 159 – 200 $\mu g/m^3$ and then Ajiad Assod (146 $\mu g/m^3$), while the lowest values were measured in Alshobikah area and were ranging between 127 – 138 $\mu g/m^3$. The reasons of these high PM_{10} concentrations in the central area sites are related to the recent construction development in the region since 2007 until now. There are other factors that have caused such high PM_{10} concentration, such as overcrowding, traffic jam, density urban area, rising numbers of attendees of the Holy Mosque and increasing different activities during Hajj season in the region. The reason of the highest concentration of PM_{10} in Alghazah, is because of the site being very close to the construction development areas. Moreover, the measurement days of 6th and 7th of Zulhijah were weekend period when most inhabitants (in addition to pilgrims) before to go to the holly Mosque. Nevertheless, PM_{10} concentrations at sites out of the central area were comparatively lower than that in the central area (Figure 1) and were ranging between 85 – 136 $\mu g/m^3$. The highest concentration of PM_{10} (136 $\mu g/m^3$) in Alaziziah area was on 10th of Zulhijah when most of pilgrims return from Mina to Makkah passing Alaziziah area to make Tawaf Alefadah and pray Eead Aladha in the Holy Mosque. As a result numbers of buses and vehicles are increasing sharply in Alazizih area causing high density of transportation and hence large PM_{10} concentration. However, the lowest PM_{10} concentration of 85 $\mu g/m^3$ was observed on 9th of Zulhijah when all pilgrims were accommodating in Arafat area for Al-Wakffah day. On 8th of Zulhijah the measured PM_{10} concentration in Alaziziah has increased to 122 $\mu g/m^3$ due to moving of most pilgrims by buses from Makkah to Mina Valley to stay tonight following the guidance of Prophet Muhammad.

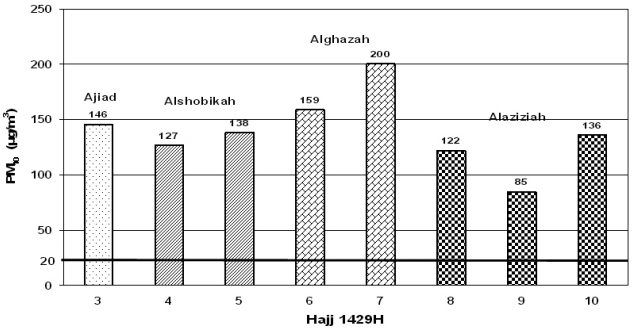

Fig. 1. Concentration of PM_{10} at four sites in Makkah during hajj 2008.

Figure 2 showed temporal variations of the measured PM_{10} concentrations at the central area in Makkah during Hajj seasons in this study (2008) against the measured one in the previous studies [*Nasralla*, 2004 - 2008] for two deferent years of 2004 and 2005. It is clear that the measured concentrations of PM_{10} in this study were generally higher than that in both years of 2004 and 2005. However, PM_{10} levels in days of 10th and 11th of Zulhijah in 2005 were higher than others. It is also observed that the concentrations of PM_{10} in days before Arafat day were greater than that after Arafat day. Nevertheless, the PM_{10} levels on all hajj days in the three years were very high and exceeded the recommended limits of PM_{10} (20 $\mu g/m^3$) by WHO.

Such high concentration of PM_{10} in Makkah could affect pilgrims' health and pilgrims may face an acute health problem [*Nasralla*, 1986] during hajj season. It is well known that long term exposure to PM_{10} concentrations can cause several diseases such as mortality due to cardiovascular, respiratory disease, chronic respiratory disease incidence and prevalence (asthma, COPD, chronic pathological changes), chronic changes in physiologic functions, lung cancer, chronic cardiovascular disease and intrauterine growth restriction (low birth weight at term, intrauterine growth retardation, small for gestational age) [*WHO*, 2005].

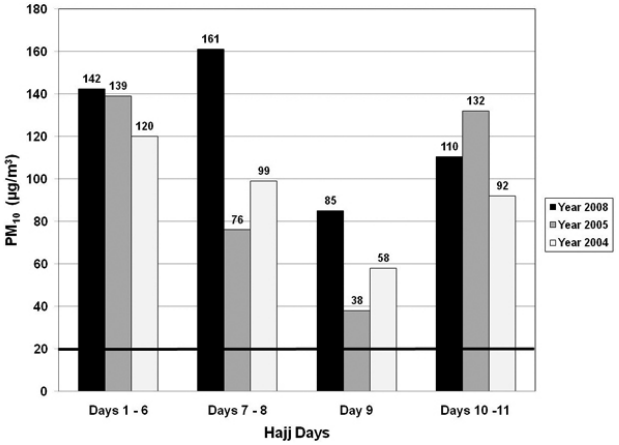

Fig. 2. Concentration of PM_{10} during hajj days in three deferent years in Makkah.

To assess the health risks for pilgrims during their residence in Makkah due to the exposure to PM_{10}, calculations were applied according to equations 1 - 4 given by WHO [*WHO*, 2000]. These equations are as following:

% 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)

Results of these health risks are presented together with the calculated one in hajj 1425H (2005) [*Nasralla*, 2004 - 2008] in Table 1 for comparison. It is clear that the predicted health risks at the central area in hajj 1429H and 1425H are similar and confirm the dangerous of these recorded PM_{10} concentrations. 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 [*Nasralla*, 2004 - 2008]. This means that sustainable solutions for decreasing PM_{10} concentrations in the central area are required soon. In fact, well planned air quality management and alternative transportation system are urgently recommended for Makkah.

Table 1. Table 1. The estimated risks on pilgrims' health during their residence at the central area in Makkah in hajj 1429H (2008).

Site	% increase in mortality	% change in hospitals admission	% change in cough	% change in symptom exacerbation
Ajiad Assod	8 - 12	7 - 17	33 - 99	27 - 74
Alshobikah	8 - 11	7 - 16	31 - 94	25 - 70
Alghazah	12 - 16	10 - 23	45 - 137	37 - 102
Alaziziah	8 - 11	7 - 16	31 - 93	25 - 69
Central area in hajj 1425H (2005)	8 - 14	10 - 14	51 - 77	39 - 59

CO concentrations

The variation of CO concentrations were sampled daily between 16:00 - 00:00 at seven sites of Alshobikah, Ajiad Assod, Alghazah, Umm Alqura Street, Tunnel_1, Alaziziah and Tunnel_2 from 3rd to 8th of Zulhijah and were presented in Figure 3. Most sites showed low CO concentrations (<20 mg/m^3) every hour during the days of Zulhijah. The variations of CO concentration in most sites were almost similar and ranging between 1 - 17 mg/m^3. However, Tunnel_1 showed higher CO concentration and reached to the maximum hourly average CO concentration of approximately 97 mg/m^3 at 17:00 exceeding the allowed hourly CO concentration of 30 mg/m^3 by both GERRI [*GERRI*, 2006] and WHO [*WHO*, 2000].

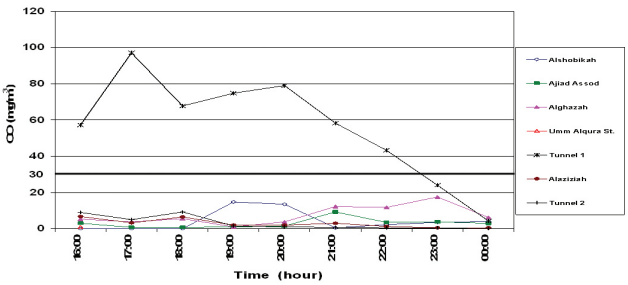

Fig. 3. Hourly averages CO Concentration at seven sites in Makkah during hajj 2008.

However, this concentration has sharply decreased between 20:00 and 00:00 when last prayer (Eshaa prayer) in the Holy Mosque has finished and most pilgrims have left to their accommodations causing low vehicle density in Tunnel_1 at this time of period. Nevertheless, CO concentration at this tunnel was still the highest due to the design of this Tunnel_1, which is not straight (Shahatah, 2003). The ventilation system inside this tunnel also causes large air turbulences and captures gases inside it, leading to high CO concentration. Another reason for such high CO concentration is the location of this Tunnel_1, which is located underneath the Holy Mosque halls, where most pilgrims and inhabitants prefer to go through for prayers. Hence, numbers of vehicles passing this Tunnel_1 are increasing sharply, especially before and after prayers.

To compare the concentration of CO among these seven sites, the average CO concentration per 8 hours were calculated and presented in Figure 4. Most sites were within the allowed CO concentration 10 mg/m^3/8hr that recommended by WHO. This is good result, confirming that the ambient air inside and outside the central area is healthy for pilgrims during the hajj season in Makkah. However, Tunnel_1 showed the highest average CO concentration among sites with value of 60 mg/m^3/8hr exceeding 6 times of the allowed value by *GERRI* (10 mg/m^3/8hr) [*GERRI*, 2006]. In addition, the average concentration of CO at Umm Alqura Street was approximately 12 mg/m^3. Figure 4 also showed that the average concentration of CO in sites at the central area were generally greater than that outside of the central area. This confirms the high

density of transportation at the central area in Makkah during the hajj season. This means that the concentrations of CO in most sites of interest at the central area are within the allowed limits (30 mg/m^3) by both *GERRI* [*GERRI*, 2006] and WHO [*WHO*, 2000] and there was no dangerous on pilgrims health during their stay in Makkah.

In addition, temporal variations of CO concentrations at the central area in Makkah during the day of 4th of Zulhijah of this study (2008) were plotted in Figure 5 against the measured one by previous studies [*Nasralla*, 2004 - 2008] in 2005. Generally, both data are similar and lower than 20 mg/m^3 that are within the allowed limits (30 mg/m^3) by both *GERRI* [*GERRI*, 2006] and WHO [*WHO*, 2000]. These findings confirm the low levels of CO concentrations in the central area in Makkah and hence safety and convenient environment for pilgrims during their stay. In fact, many direct experiments investigating the effects of CO on humans have been conducted during the last century [*WHO*, 1999]. Such effects include acute pulmonary, cardiovascular and respiratory response to exercise and behavioural changes and work performance [*WHO*, 1999].

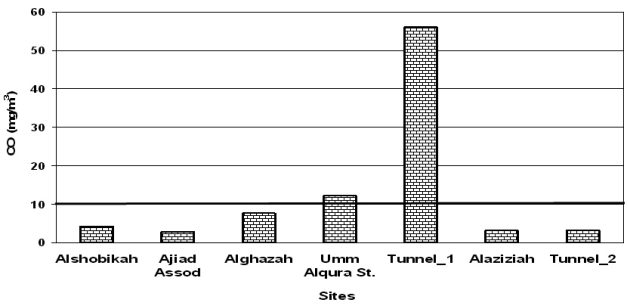

Fig. 4. The average CO Concentration per 8 hr at seven sites in Makkah during hajj 2008.

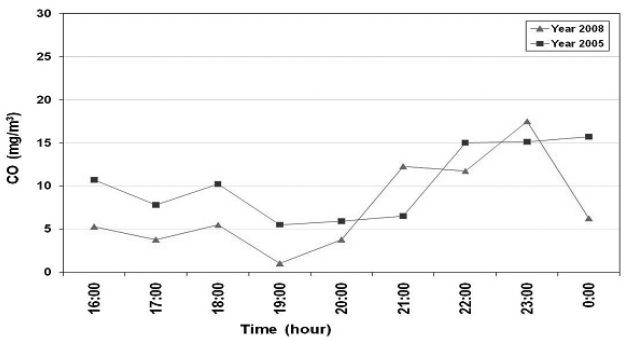

Fig. 5. Temporal variations of CO concentrations at the central area in Makkah during the day of 4th of Zulhijah in years 2005 and 2008.

Noise levels

Measurements of noise levels were conducted daily between 16:00 and 00:00 at most sites inside and outside of the central area. Measurements have included three kinds of noise functions of LAeq, Lmax and Peak. Figure 6 showed the noise levels of three functions in Alghazah site on 4th of Zulhijah. The LAeq values were ranging between 71 - 92 dB exceeding the recommended values of 70 dB in traffic areas by WHO [*WHO*, 1999]. Moreover, the highest values of Lmax and Peak were approximately 111 and 121 dB, respectively. However, the maximum noise level of LAeq (92 dB) was recorded at 21:30 after Esha prayer due to the traffic road at this time.

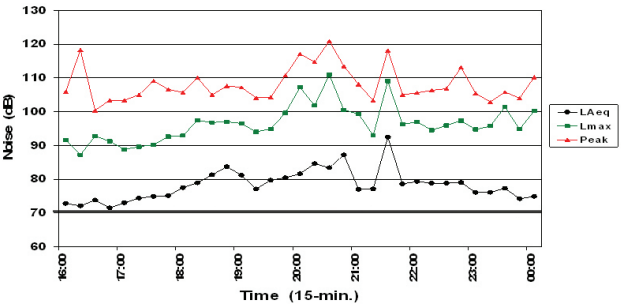

Fig. 6. Variation of the three noise functions in Alghazah site on 4th of hajj 2008.

The LAeq values at sites of Ajiad Assod, Alghazah, Umm Alqura Street, Tunnel_1, Alaziziah and Tunnel_2 were measured from 2nd to 6th of Zulhijah and presented in Figure 7. In general, most sites showed high noise levels ranging between 71 – 98 dB exceeding the recommended value by WHO in most time of measurements. The curves fluctuations at sites are due to the variation in numbers of cars per each 15 minutes that are related to the different times of prayers during the day. The daily measured noises levels of LAeq (8 hours) at these six sites were computed using an algorithm equation of 5 and presented in Figure 8 for comparison.

$Leq = 10*\log_{10}\{(10^{(Leq(1)/10)} + 10^{(Leq(2)/10)} + \ldots\ldots 10^{(Leq(n)/10)})/n\}$……..(5)

Where n = number of noise level samples.

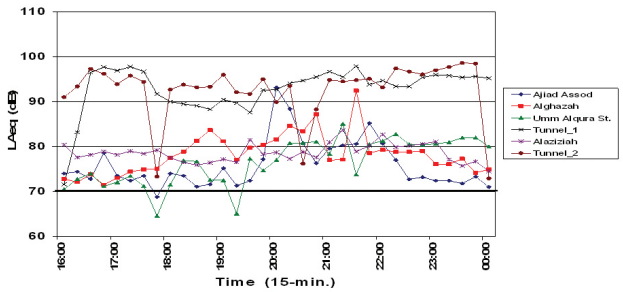

Fig. 7. Variations of LAeq levels per 15 min at six sites in Makkah during hajj 2008.

Most sites except both tunnels have shown noise levels of approximately 81 dB even inside and outside the central area. However, both tunnels showed the highest level of LAeq of about 94 dB. The reason of these high noise levels in both tunnels is because these are closed areas and many cars (400 – 750 cars) were passing these tunnels at every 15 minutes during the time of

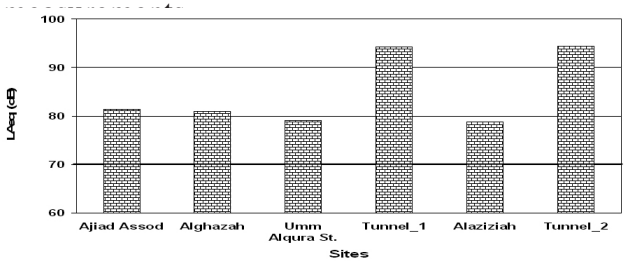

Fig. 8. The daily average levels of LAeq per 8 hr at six sites in Makkah during hajj 2008.

In fact, all these measured noise levels of LAeq at the central area are exceeding the recommended noise levels by WHO of 70 dB at traffic areas [*WHO*, 1999] and even by other international threshold of noise level of 65 dB [*Ali and Tamura*, 2002; *Barrigon-Morillas, et al.*, 2005]. Such high noise levels could cause several health problems for pilgrims, which in turn can affect their behaviours. It is approved that high noise levels can cause speach intelligibility [*Bradley*, 1986], sleep disturbance [*Cohen, et al.*, 1986], mental health problems [*WHO*, 1999], physiological effects, such as tiredness and hypertension [*IEH*, 1997; *Ising, et al.*, 1998]. However, these noise effects are very dependent on specific factors, such as the time duration, noise source level, and the distance from the source. Therefore, knowing noise sources can extremely help us to control the levels of noise and manage it properly.

Statistical Analysis

Statistical analysis was made in order to inspect significant differences among the levels of PM_{10}, CO and Noise data. Two-way analysis of variance (ANOVA) has been conducted using the MINITAB computer package. However, PM_{10} variable was too few to conduct ANOVA. So, the basic characteristics of the data were just described in this aspect. The grand mean of PM_{10} values over all the period time of measurement was about 139 $\mu g/m^3$. The average percentage difference of PM_{10} value in Alghazah area was greater than the grand mean with about 29.2%, while this average percentage of PM_{10} value was more than the grand mean with approximately 4.6% in Ajiad Assod area. On the other side, these average percentage of PM_{10} values were lower than the grand mean value with about 17.9% and 4.7% in Alaziziah and Alshobikah areas respectively.

Unlike PM_{10} variable, the data of both CO and Noise variables were more than enough to conduct two-way analysis of variance (ANOVA) and results are reported in Tables 2 and 3 for CO and Noise respectively. The two-way analysis of variance (ANOVA) of CO levels showed that the P value corresponding to the times factor was 0.593, which is much bigger than the level of significance 0.05. This means that there are no significant differences in CO levels among the times. However, the ANOVA showed that the P value corresponding to the places factor was almost 0.000, which is much lower than any level of significance meaning that there are significant differences in CO levels among the selected places.

In term of noise levels, the two-way ANOVA showed that the P value corresponding to the times factor was 0.002, which is much less than the level of significance 0.05. This means that there are significant differences in noise levels among the times. In addition, the P value corresponding to the places factor was almost 0.000, which is much lower than any level of significance. This means that there are also significant differences in noise levels among the places.

Air pollution and Noise sources

The central area of Makkah is characterized by very highly dense population, high buildings, narrow streets, and congested traffic flow. The high rates of pollutant emissions from vehicle exhausts are the main source of air pollution, especially in such small central area surrounded by mountains. Congestion and predominant weather conditions also increase the problem in such small central area. Measurements of weather conditions in this study showed that high temperature (35°C), high relative humidity (70%), prevailing one wind direction (South west), low wind speed of approximately 3 m/s, lack of rainfall and the potentiality of thermal inversions make the area an ideal situation for the accumulation of air pollutants. In term of noise sources in the central area, sources are mainly related to transportation, shops and crowdedness of pilgrims and inhabitant. Hence, quicker and sustainable solutions are required to control and diminish both air and noise pollutions at the central area in Makkah. It is suggested that adoption of a new technical and public transportation system at this central area such as monorail, trams or train networks would extremely diminish PM_{10} and pollutants, as well as noise levels. Sirens of buses, alarm of ambulance and governmental vehicles should not be used at the central area except on emergency cases. As a result a big challenge of air and noise pollutions is faced every year in hajj season, which requires a comprehensive solution to manage these problems and continuing evaluation of air quality at the central area to provide quite and healthy ambient for pilgrims.

Table 2. Two-way ANOVA of CO levels at the central area in Makkah in hajj 1429H (2008).

Source	DF	SS	MS	F	P
Times	8	771.2	96.39	0.81	0.593
Places	7	21351.6	3050.23	25.77	0.000
Error	56	6627.5	118.35		
Total	71	28750.3			

Table 3. Two-way ANOVA of Noise levels at the central area in Makkah in hajj 1429H (2008).

Source	DF	SS	MS	F	P
Times	34	1518.5	44.66	1.98	0.002
Places	5	10927.1	2185.43	96.88	0.000
Error	170	3835.0	22.56		
Total	209	16280.6			

CONCLUSIONS

Temporal and spatial variations in the concentrations of PM10 and CO as well as noise levels were measured at the central area in Makkah, Saudi Arabia during hajj season in 1429H (2008). Results showed high concentration of PM_{10} at the central area ranging between 85 – 200 $\mu g/m^3$. However, the CO concentration was almost less than 20 $mg/m^3/hr$ at most central area sites except Tunnel (1) that increased to a level of 97 $mg/m^3/hr$. The equivalent noise levels of LAeq at the central area varied between 71 – 98 dB levels exceeded the recommended value of 70 dB by WHO. Adopting a new technical and public transportation system is considered as the main recommendation of study here.

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