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Estimation of PM_{10} Health Impacts on Human within Urban Areas of Makkah city, KSA

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Abstract
The current study aimed to: i) Monitor levels of PM_{10}, at Shebika, Haram, Masfala, Azizia, Awali and Mina in Makkah city, KSA during the period of 01 Shawwal 1436H – 27 Rabi Al-Awwal 1437H, by using LVS instruments; and; 2) assess health risk (non-cancer and cancer risks) on humans (children and adult) exposed to PM_{10} in ambient air of Makkah city.
The results showed that: the high PM_{10} levels were found in Haram site, while the lower levels were found in Awali site. These levels were lower than that set for PM_{10} by PME (Daily limit of 340 μg/m^3). Vehicles emissions and constructions sources may be the main source of PM_{10} levels in Makkah city. The human health risk assessments showed that: the daily exposure doses of PM_{10} were ranked in the order: $D_{ing} > D_{dermal} > D_{inh}$ for children and adult in Makkah city. Ingestion of PM_{10} particles was the main exposure pathway for both children and adults. The HIs and cancer risk values were within the safe level, indicating that (non-carcinogenic and carcinogenic) risks for humans exposed to PM_{10} in Makkah city were negligible.

Keywords: PM_{10}, Exposure, Health risk assessment, Makkah.

Introduction

Respirable particulate matter (PM_{10}) was particles with a diameter ≤ 10. PM_{10} was a complex mixture of dust, salt, acids, organic matter and metals; which varied in levels, composition and sources (Pope and Dockey, 2006). Human Exposed to PM_{10} might be affected by definite (cancer and non cancer) risks (Hnizdo and Vallyathan, 2003, Davies, 2012). The health impact of children and adults exposed to PM_{10} in ambient air were reported in several studies like: ATS, 1997; Batterman et al., 2011**;** Thabethe et al., 2014. PM_{10} in ambient air were easily enter the human body via three primary pathways: inhalation (through mouth and nose, which may reach the alveolar in the lung), ingestion (through mouth and nose), and Dermal absorption of particles adhered to exposed skin contact (US EPA, 1989; 2004; Darquenne et al., 2000; Ferreira and De Miguel, 2005; Ahmed and Ishiga, 2006; Zheng et al., 2010a, 2010b; Lu et al., 2014; Xu et al., 2015). The levels and health risks of PM_{10} exposed to humans were evaluated in different previous studies such as: Apeagyei *et al*., 2011; Tang et al., 2013; Kexin et al., 2015. However, the most previous studies focused on PM_{10} in capital cities or mega-cities, which characterized by traffic density and over population. There was lake in that studies in Makkah city and the other cities in Kingdom Saudi Arabia (KSA).
The major sources of PM_{10} in ambient air of Makkah city include: vehicles emissions, construction; paved roads; unpaved roads, power plant emissions and windblown dust from open lands. Given these air pollution sources, it was deemed necessary to estimate the likely human health risks posed by PM_{10} to the residents of Makkah city, an activity never done before for this geographic region, for future planning and management of air pollution in the area. The main objectives of this study were to: i) Monitor levels of PM_{10}, mainly emitted in urban sites at Makkah city, KSA; and 2) evaluate health risk (non-cancer and cancer risks) associated with PM_{10} exposure for children and adult in Makkah city.

Materials and methods

Study area and sampling sites description

The current study; PM_{10} samples were collected from ambient air at 6 sites located in Makkah city, KSA (Fig.1). Makkah city is located 70 km inland from Jeddah in a narrow valley at a height of 277 m above sea level. Makkah city lies in a corridor between mountains. This mountainous location has defined the contemporary expansion of the city. The total area of Makkah stands over 1,200 km^2. Its resident populations in 2014 were roughly (1,919,909 people ≈ 2 million), although visitors (pilgrims) more than 6,000,000 people every year during the hajj and Umraa seasons (Statistical Yearbook, 2014). The brief descriptions of the sampling sites were given in Table 1.

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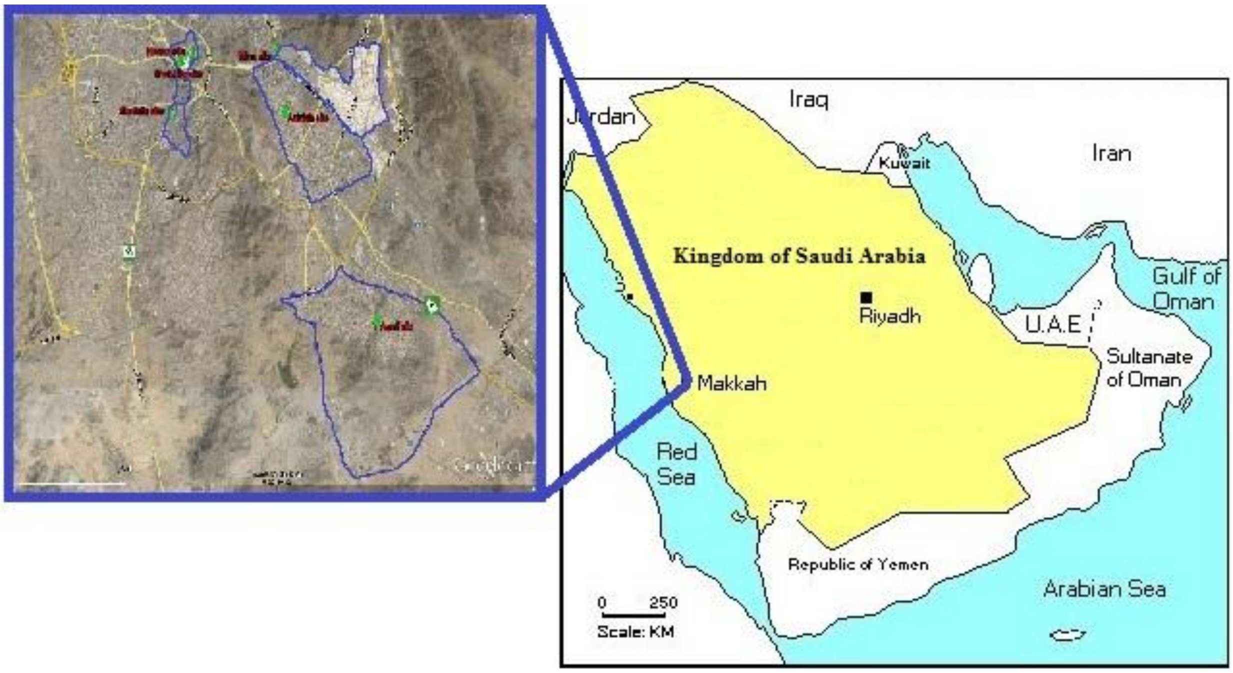

Figure 1: Sampling sites in Makkah city, Kingdom of Saudi Arabia (KSA).

Table 1: Sampling sites description

Site Name	Brief description
Shebaika	• Upper small market tunnel. • In center of the south squares of the Holy Mosque. • Generally a very busy location in terms of prayers. • High density of prayers was present during sampling period.
Haram	• Upper small market tunnel. • Downwind from the south squares of the Holy Mosque and situated near bathrooms. • Had a high density of prayers during sampling period.
Masfalla	• Upper small market tunnel. • Upwind from the south squares of the Holy Mosque. • Had high density of prayers during sampling period.
Aziziah	• Lower south squares of the Holy Mosque. • Likewise a busy location and had a high traffic density during sampling period.
Awali	• New area. • Quiet residential area famous by villas and some facilities such as petrol stations and supermarkets. • Near to Taif Road and the mountains.
Mina	• Desert area about 5 km east of Makkah. • The area is known for its important role for pilgrims, where many pilgrims stay on a temporary basis during hajj.

Sampling Method

LVS (Low Volume Sampler) were used to collect respirable particulate matter (PM_{10}) in 6 sites. Samples were collected weekly during the period from 1 Shawwal 1436 AH - 27 Rabi al-Awwal 1437 AH, collecting a total of 30 samples, the sampling time was 24 h. LVS manufactured by the German Beko (Beco R300), which calibrated before device used. LVS were use nitrate cellulose filters with size of 0.45 microns for dust least 10 micrometers (Fig.2). 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 $\mu g/m^3$ (JIS, 1992).

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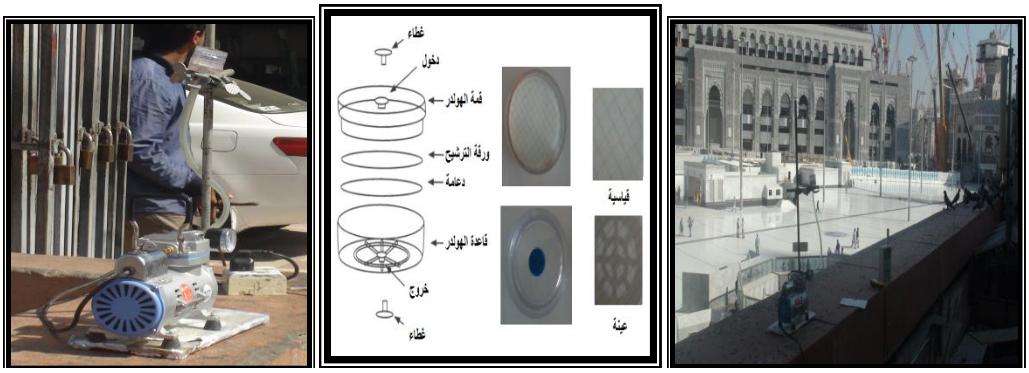

Fig. 2: Low Volume Sampler (LVS) and PM_{10} holder.

Health Risk Assessment

The Daily Exposure dose (D)

In the current study, the health risk assessment model developed by the Environmental Protection Agency of the United States (US EPA) was used to evaluate the health risks of PM_{10} in Makkah city, KSA. Peoples in Makkah city (local residents and pilgrims) were divided into adults and children. Human were exposed to PM_{10} in ambient air via three primary pathways: i) Inhalation of suspended particles through mouth and nose (D_{inh}); ii) Ingestion of dust particles through mouth (D_{ing}); and iii) Dermal absorption of PM_{10} particles adhered to exposed skin (D_{dermal}). The daily exposure dose (D) of PM_{10} calculated separately for each exposure pathway according to equations (1, 2, and 3) (US EPA, 1989; 2004). Exposure was expressed in terms of daily dose (mg/kg.day).The exposure factors for these models were shown in Table 2.

$$D_{ing} = \frac{C \times IngR \times EF \times ED \times CF}{BW \times AT} \quad \text{.................................} \quad \textbf{Eq. 1}$$

$$D_{inh} = \frac{C \times InhR \times EF \times ED}{BW \times AT \times PEF} \quad \text{.................................} \quad \textbf{Eq. 2}$$

$$D_{dermal} = \frac{C \times SA \times SL \times ABS \times EF \times ED \times CF}{BW \times AT} \quad \text{.......................} \quad \textbf{Eq. 3}$$

The average daily dose (ADD) = $D_{ing} + D_{inh} + D_{dermal}$ **..................... Eq.4**

Table 2: Exposure factors.

Factor	**Definition**	**Value**		**Unit**	**Reference**
		Adults	**Children**		
C	PM_{10} concentrations	Measured		mg/m^3	The current study
D_{ing}	The ingestion daily exposure dose	Calculated		mg/kg . day	
D_{inh}	The inhalation daily exposure dose				
D_{dermal}	The dermal daily exposure dose				
ADD	The average daily dose				
BW	Average body weight	70	15	kg	US EPA, 1989
IngR	Ingestion rate	100	200	mg/day	
InhR	Inhalation rate	20	7.6	m^3/day	Zheng et al., 2010a
PEF	Particle emission factor	1.36×109		m^3/kg	US EPA, 2001
SA	Surface areas of the skin that contacts the airborne particulates	5700	2800	cm^{-2}	US EPA, 2004
SL	Skin adherence factor	0.07	0.2	mg/m^3	
EF	Exposure frequency	180	180	Days/year	Zheng et al., 2010a

Factor	Definition	Value		Unit	Reference
		Adults	Children		
ED	Exposure duration	24	6	Years	US EPA, 2001
AT (non-cancer risk)	Averaging time	ED×365		Days	
AT (cancer risk)	Averaging time	70×365		Days	
ABS	Dermal absorption factor	0.001		Unitless	US EPA, 2011
CF	Conversion factor	1×10-6		Kg/mg	US EPA, 2004

Risk Assessment

Hazard quotients (HQ) for non-carcinogenic effects were applied to each exposure pathway in the analysis to evaluate the non-carcinogenic risks due to PM_{10} in ambient air of Makkah city, KSA. The daily exposure doses calculated for each exposure pathway were subsequently divided by the reference dose of PM_{10} (RfD = $1.1x10^{-2}$ mg/kg.day, Zou et al., 2009) to yield a hazard quotients (HQs) according to equation 5 (US EPA, 1989, 1996):

$$HQ = D / RfD \quad \text{…………………… Eq.5}$$

The hazard index (HI) was then the sum of HQs and was used to represent the total potential non-carcinogenic risks of PM_{10} in ambient air of Makkah city, KSA. If (HI < 1), there was no significant risk of non-carcinogenic effects. If (HI > 1), then there was a chance that non-carcinogenic effects may occur (US EPA, 1989; US EPA, 2001; Ferreira and Miguel, 2005; Lim et al., 2008; Zheng et al., 2010a,b; Xu et al., 2015). In the case of carcinogenic risks, the dose was multiplied by the slope factor of PM_{10} (SF = 2×10^{-6} $(mg/kg.day)^{-1}$, Vallero, 2014) to produce a level of cancer risk according to equation 6:

$$R = ADD \times SF \quad \text{……………………. Eq.5}$$

Carcinogenic risk is the probability of an individual developing any type of cancer from lifetime exposure to carcinogenic hazards. EPA considered cancer risks between 10^{-6} (i.e., 1 in 1,000,000 people) and 10^{-4} (i.e., 1 in 10,000 people) to be generally acceptable (US EPA, 1991b). Cancer risks higher than 10^{-4} might not be considered sufficiently protective and many warrant remedial action (Lim et al., 2008; US EPA, 2009a).

Results and Discussions

PM_{10} concentrations

The daily average respirable particulate matter (PM_{10}) concentrations in ambient air of 6 sampling sites in Makkah city were measured during period from 1 Shawwal 1436 AH - 27 Rabi al-Awwal 1437 AH (as shown in Fig.3). LVS instruments was used to collect samples. The PM_{10} concentrations measured were generally higher in Haram site (343 µg/m^3) than the PM_{10} concentrations measured in Awali site (64 µg/m^3). These concentrations were lower than the PME Daily limit of 340 µg/m^3 on most of the days, except in Haram site (PME, 2001). Which means that even if the population of Makkah was exposed to that levels of PM_{10}, negative health impacts may be unlikely, as concentrations were below the daily average limit of PME, although some individuals may still be sensitive to relatively low PM_{10} concentrations (WHO, 2006). The current study attributed concentrations obtained of PM_{10} to greatest efforts exerted by the Government of the Kingdom of Saudi Arabia represented by the executive authorities in the city of Makkah Al Mukarramah (such as the Holy City, the Holy City Secretariat and the General Presidency of the Holy Mosque) in providing clean air and environment free from harmful air pollutants to take care pilgrims. Moreover, Presence of sprayers located in the squares, which helps to deposit and reduce the dust suspended in the air. Furthermore, The presence of hotels surrounding the areas, which act as windbreakers loaded with airborne dust, and helps to re-establish and reduce its concentrations in the squares. In addition, Rainfall on the city of Mecca during the measurement period, which helped to purify ambient air and deposit dust. In Makkah the major factor responsible for the high emission of PM_{10} is probably the higher number of visitors to the Holy Mosque during Hajj season (Zul-Qaadah - Zul-Hijjah), that leads to higher traffic flow on roads around the Holy Mosque in Makkah city (elevated vehicle emission levels). Table 3 showed comparison between levels of PM_{10} in the current study and levels found in other cities around the world.

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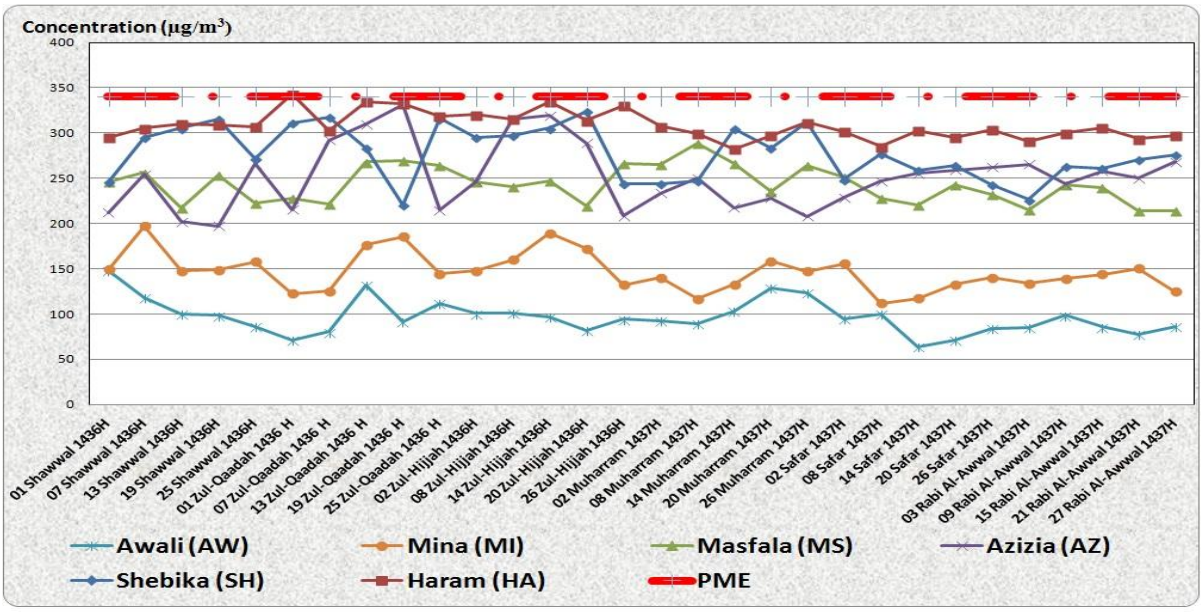

Fig.3: Daily mean levels of PM_{10} during sampling period.

Table 3: Comparison between levels of PM_{10}.

Country	PM_{10} (µg/m^3)	Reference
Saudi Arabia		
- **Makkah**	64 - 343	The current study
- **Jeddah**	87.3	Khodeir et al., 2012
- **Riyadh**	54.0	US EPA, 2013
UAE	157	Al Katheeri et al., 2012
Kuwait	93	Brown et al., 2008
Lebanon	103	Saliba et al., 2010
India	285	Bhagia, 2012
Italy	2.9	WDNR, 2011
UK	150	IARC, 2005
Finland	12.8	Richards and Brozell, 2015
Canada	8.7	EC, 2011
Australia	32.5	MPCA, 2015
USA	34	US EPA, 2006

Health Risk assessment

The Daily Exposure doses (D)

Table 4 and 5 represented the daily exposure dose of PM_{10} for both children and adults in sampling sites at Makkah city, KSA environments. The average daily exposure doses (ADD) were (children: 6E-07 - 2E-06; Adult: 7E-08 - 2E-07 mg/kg.day) and (Children: 5E-08 - 2E-07; Adult: 2E-08 - 7E-08 mg/kg.day) for non cancer risk and for cancer risk, respectively). Furthermore, Table 4 and 5 showed the higher ADD were found for children and adults at Haram site, while low ADD were found at Awali. In the case of non cancer risk, the daily doses of PM_{10} at all sampling sites were (Children: 6E-07 - 2E-06; Adult: 7E-08 - 2E-07 mg/kg.day), (Children: 2E-11 - 6E-11; Adult: 1E-11 - 3E-11 mg/kg.day), and (Children: 2E-09 - 6E-09; Adult: 3E-10 - 9E-10 mg/kg.day) by ingestion (D_{ing}), inhalation (D_{inh}), and dermal contact (D_{dermal}), respectively (Table 4). While in case of cancer risk, the daily doses of PM_{10} at all sampling sites were (Children: 5E-08 - 2E-07; Adult: 2E-08 - 7E-08 mg/kg.day), (Children: 2E-12 - 5E-12; Adult: 3E-12 - 1E-12 mg/kg.day), and (Children: 2E-10 - 5E-10; Adult: 9E-11 - 3E-10 mg/kg.day) by ingestion (D_{ing}), inhalation (D_{inh}), and dermal contact (D_{dermal}), respectively (Table 5). In the current study, the daily doses of PM_{10} were ranked in the order: D_{ing} > D_{dermal} > D_{inh} for children and adult for non-cancer risk and cancer risk at all sampling sites.

Table 4: The daily exposure doses for non cancer risk

Site	D_{inh}		D_{dermal}		D_{ing}		ADD (mg/kg . Day)	
	Children	Adult	Children	Adult	Children	Adult	Children	Adult
Shebika (SH)	5E-11	3E-11	5E-09	8E-10	2E-06	2E-07	2E-06	2E-07
Haram (HA)	6E-11	3E-11	6E-09	9E-10	2E-06	2E-07	2E-06	2E-07
Masfala (MS)	4E-11	3E-11	4E-09	7E-10	2E-06	2E-07	2E-06	2E-07
Azizia (AZ)	5E-11	3E-11	5E-09	7E-10	2E-06	2E-07	2E-06	2E-07
Awali (AW)	2E-11	1E-11	2E-09	3E-10	6E-07	7E-08	6E-07	7E-08
Mina (MI)	3E-11	2E-11	3E-09	4E-10	1E-06	1E-07	1E-06	1E-07

Table 5: The daily exposure doses for cancer risk

Site	D_{inh}		D_{dermal}		D_{ing}		ADD (mg/kg . Day)	
	Children	Adult	Children	Adult	Children	Adult	Children	Adult
Shebika (SH)	5E-11	3E-11	5E-09	8E-10	2E-06	2E-07	2E-06	2E-07
Haram (HA)	6E-11	3E-11	6E-09	9E-10	2E-06	2E-07	2E-06	2E-07
Masfala (MS)	4E-11	3E-11	4E-09	7E-10	2E-06	2E-07	2E-06	2E-07
Azizia (AZ)	5E-11	3E-11	5E-09	7E-10	2E-06	2E-07	2E-06	2E-07
Awali (AW)	2E-11	1E-11	2E-09	3E-10	6E-07	7E-08	6E-07	7E-08
Mina (MI)	3E-11	2E-11	3E-09	4E-10	1E-06	1E-07	1E-06	1E-07

Non-carcinogenic risk assessment

The results of the hazard quotient (HQ) values of different exposure pathways (D_{ing}, D_{inh}, and D_{dermal}), hazard index (HI) for both children and adults in sampling sites at Makkah city were calculated in Table 6. Among three different exposure pathways, the HQ_{ing} values were the highest and contributed the most to HIs for both children and adults at all sites, indicating that ingestion of PM_{10} appears to be the most threatening exposure way to human health in Makkah city (Fig. 4). The HQs for all studied sites were ranked in the order: HQ_{ing} > HQ_{dermal} > HQ_{inh} for children and adult. Results also showed that the inhalation of PM_{10} had the lowest contribution to health risks for children and adults, indicating that the non-cancer risks posed by the inhalation of PM_{10} might be negligible compared with ingestion and dermal contact. Similar results were obtained by previous studies (Ferreira and De Miguel, 2005; Zheng *et al*., 2010a; OSHA, 2013). Additionally, children were found to experience higher health risks through ingestion compared with adults. The values of HQ_{ing} for children were 9.3 times higher than those for adults. This result may be partially attributed to the special behavior patterns of children, particularly frequent hand-to-mouth contact. Similar results were obtained by (Kexin et al., 2015) where they reported The values of HQ_{ing} for children were 9.33 times higher than those for adults.

Table 6: HQs and HIs for non-carcinogenic PM_{10}.

Site	HQ_{inh}		HQ_{ing}		HQ_{dermal}		HI	
	Children	Adult	Children	Adult	Children	Adult	Children	Adult
Shebika (SH)	5E-09	3E-09	2E-04	2E-05	5E-07	7E-08	2E-04	2E-05
Haram (HA)	5E-09	3E-09	2E-04	2E-05	5E-07	8E-08	2E-04	2E-05
Masfala (MS)	4E-09	2E-09	1E-04	2E-05	4E-07	6E-08	1E-04	2E-05
Azizia (AZ)	4E-09	2E-09	2E-04	2E-05	4E-07	6E-08	2E-04	2E-05
Awali (AW)	2E-09	9E-10	6E-05	6E-06	2E-07	2E-08	6E-05	6E-06

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Site	HQ_{inh}		HQ_{ing}		HQ_{dermal}		HI	
	Children	Adult	Children	Adult	Children	Adult	Children	Adult
Mina (MI)	2E-09	1E-09	9E-05	9E-06	2E-07	4E-08	9E-05	9E-06
						HI for Makkah	**8E-04**	**9E-05**

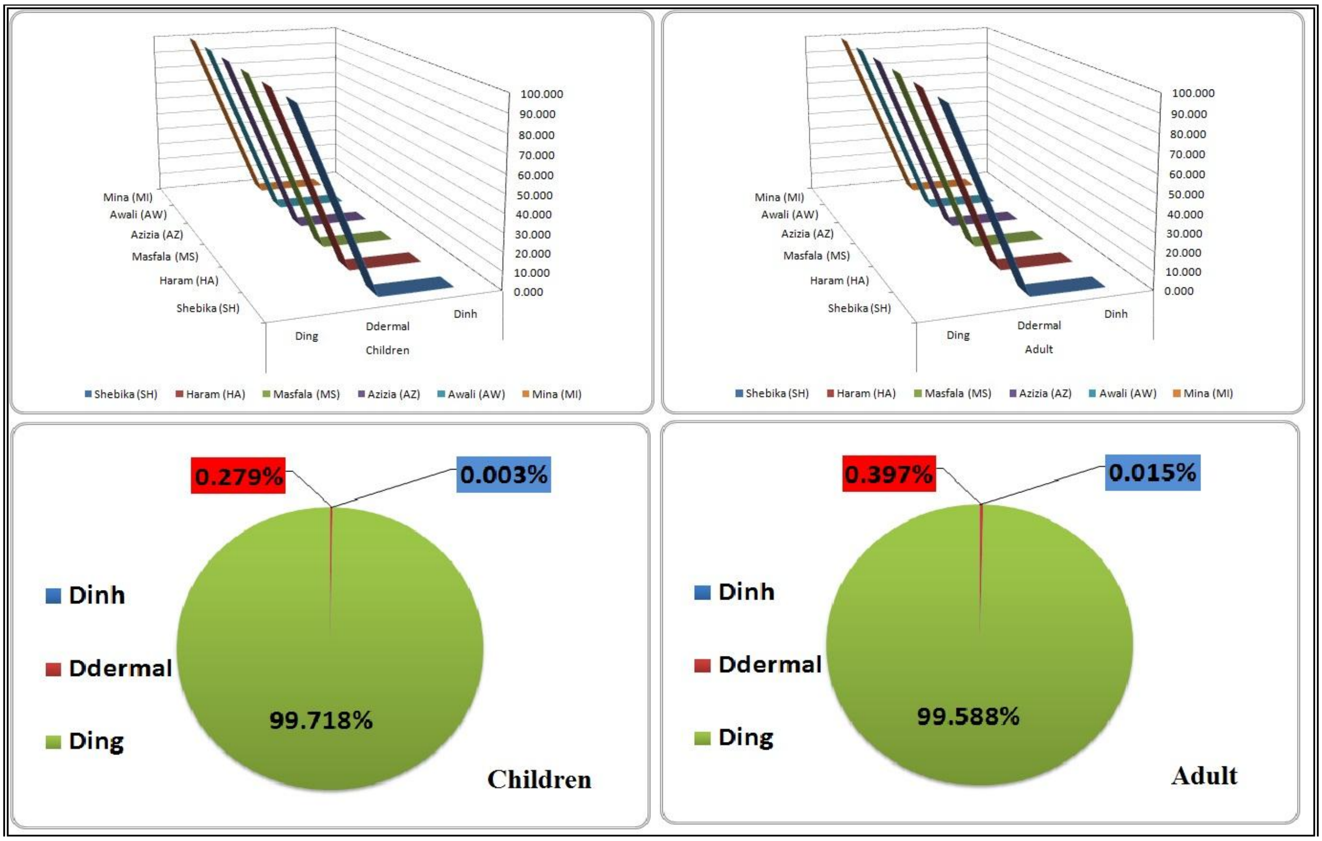

Figure 4: Non-carcinogenic risk distribution of different exposure ways for children and adults in Makkah.

The HIs for all studied sites were ranked in the order: $HI_{ing} > HI_{dermal} > HI_{inh}$ for children and adult. (Table 6). The integrated HI values in Makkah city were 8E-04 for children and 9E-05 for adults, indicating children are likely to experience significantly higher non-cancer risks. The HI values for all sampling sites in this study were within the safe level (HI < 1) , this results indicated that there was no significant risk of non-carcinogenic to children and adults from exposure to PM_{10} levels in Makkah city. Similar results were obtained by previous studies (EPA, 1989; USEPA, 2001; Ferreira and Miguel, 2005; Lim et al., 2008; Zheng et al., 2010a,b; Xu et al., 2015).

Carcinogenic risk assessment

The results of the cancer risks according to different exposure pathways (D_{ing}, D_{inh}, and D_{dermal}), for both children and adults in sampling sites at Makkah city were presented in Table 7. The R_{ing} values were the highest and contributed the most to cancer risk for both children and adults at all sites, indicating that ingestion of PM_{10} appears to be the most exposure way to human cancer risk in Makkah city (Fig. 5). The cancer risk for all sampling sites were ranked in the order: $R_{ing} > R_{dermal} > R_{inh}$ for children and adult. Results also showed that the inhalation of PM_{10} had the lowest contribution to health risks for children and adults, indicating that the cancer risks posed by the inhalation of PM_{10} might be negligible compared with ingestion and dermal contact. Similar results were obtained by previous studies (Ferreira and De Miguel, 2005; Zheng *et al*., 2010a). The cancer risk values in Makkah city were 1E-12 (i.e., 1 in 1,000,000,000,000 people) for children and 6E-13 (i.e., 6 in 10,000,000,000,000 people) for adults, indicating children and likely to experience significantly negligible cancer risks. The cancer risk values for all sampling sites in this study were within the safe level (10^{-6} (i.e.) 1 in 1,000,000 people and 10^{-4} (i.e.) 1 in 10,000 people; US EPA, 1991b). This results indicated that cancer risk values for Makkah city in this study were within the acceptable range, implying negligible carcinogenic risk. Similar results were obtained by previous studies (Lim et al., 2008; US EPA, 2009a).

Table 7: Cancer risks for PM_{10} in Makkah.

Site	cancer risk							
	R_{inh}		R_{ing}		R_{dermal}		Risk	
	Children	Adult	Children	Adult	Children	Adult	Children	Adult
Shebika (SH)	9E-18	2E-17	3E-13	1E-13	9E-16	5E-16	3E-13	1E-13
Haram (HA)	1E-17	2E-17	3E-13	1E-13	1E-15	6E-16	3E-13	1E-13
Masfala (MS)	8E-18	2E-17	3E-13	1E-13	8E-16	5E-16	3E-13	1E-13
Azizia (AZ)	8E-18	2E-17	3E-13	1E-13	8E-16	5E-16	3E-13	1E-13
Awali (AW)	3E-18	7E-18	1E-13	5E-14	3E-16	2E-16	1E-13	5E-14
Mina (MI)	5E-18	1E-17	2E-13	7E-14	5E-16	3E-16	2E-13	7E-14
					Cancer risk of Makkah		1E-12	6E-13

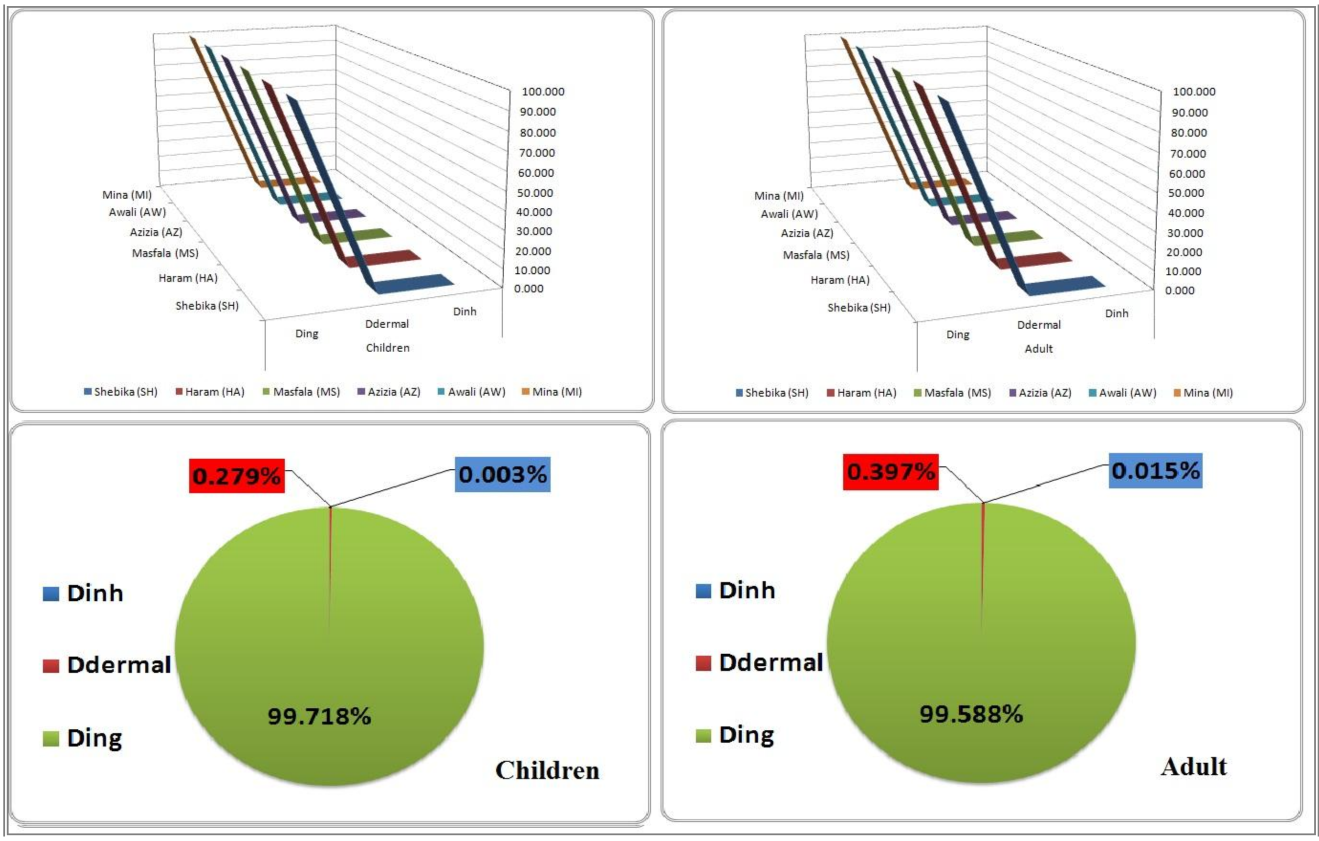

Figure 5: Cancer risks distribution of different exposure ways for children and adults in Makkah.

Conclusions

A total of 30 respirable particulate matter (PM_{10}) samples were collected from 6 sites (Shebika, Haram, Masfala, Azizia, Awali and Mina) in Makkah city, KSA during the period of 01 Shawwal 1436H – 27 Rabi Al-Awwal 1437H, by using LVS instruments. The concentration of PM_{10} were analyzed. Human health risks for PM_{10} were assessed using health risk assessment model.

Results showed that: i) The maximum PM_{10} concentrations were found in Haram site (343 µg/m^3) and the minimum in Awali site (64 µg/m^3). These concentrations were lower than the PME Daily limit of 340 µg/m^3, except in Haram site. ii)Vehicles emissions and constructions sources may contribute mostly to the levels of PM_{10} in Makkah city. iii) The health risks analysis showed that children and adult were at nearly equal risk from exposed to the same levels of PM_{10} for the same duration. The

daily exposure doses of PM_{10} were ranked in the order: $D_{ing} > D_{dermal} > D_{inh}$ for children and adult for non-cancer risk and cancer risk at all sampling sites. Ingestion was the dominant exposure pathway for both children and adults. The inhalation of PM_{10} had the lowest contribution to health risks for children and adults, indicating that the inhalation of PM_{10} might be negligible compared with ingestion and dermal contact. The values of HQ_{ing} for children were 9.3 times higher than those for adults. The HIs values for all sampling sites were within the safe level (HI < 1). The cancer risk values for all sampling sites were within the safe level (10^{-6} (i.e.) 1 in 1,000,000 people and 10^{-4} (i.e.) 1 in 10,000 people). The cancer risk values for PM_{10} in Makkah city were within the acceptable range, implying negligible carcinogenic risk.
More studies should be conducted to assess the indoor exposure to air pollution focussing on the more vulnerable groups such as infants, students, women, and the elderly and those suffering from other respiratory and cardiovascular diseases.

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