Factors Affecting PM₁₀ Levels in the Atmosphere of the Industrial Area in Jeddah, Saudi Arabia

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Abstract. Data describing PM₁₀ concentrations and some meteorological parameters (temperature, relative humidity and wind speeds) during January 2011- December 2011 were analyzed and evaluated. They were collected from an ambient air quality station in the industrial area in south Jeddah. The monthly and seasonal variations of PM₁₀ concentrations and factors affecting them were evaluated. It was found that the daily average concentrations of PM₁₀ ranged from 45 to 506 µg/m³ with a mean value of 119 µg/m³ during the period of study. Almost all the mean 24-h concentrations of PM₁₀ exceeded the WHO air quality standards for maximum 24-h concentration (50 µg/m³). The highest concentrations of PM₁₀ were found in spring, whereas the lowest levels were detected in autumn season. The mean daily concentrations of PM₁₀ were 120, 144, 116 and 89 µg/m³ in winter, spring, summer and autumn, respectively. PM₁₀ concentrations were relatively higher in weekdays than weekends during the different seasons. The weekdays/weekends concentration ratios were 1.18 (winter), 1.36 (spring), 1.41 (summer), 1.29 (autumn) and 1.32 (annual). PM₁₀ concentrations were higher in dust storm compared to non- dust storm days. The dust storm /non- dust storm concentration ratios was 3.14.

Keywords: PM₁₀, Temporal and seasonal variation, Weekdays, weekends, Dust storm, Industrial area, Jeddah.

Introduction

Ambient aerosols represent the most important one of air pollutant groups, since they play an important role in many atmospheric processes. They can affect air quality, human health, climate change directly or indirectly, visibility, agricultural and natural ecosystems, material and cultural heritages (Rajamani and Yadav, 2006; Yuan *et al.*, 2006; Yarkin and Bayram, 2008; Pérez, *et al.*, 2008; Viana, *et al.*, 2008; Stanek *et al.*, 2011; Jahn, *et al.*, 2011), and play a major role in acidification of precipitation, and earth's radiation balance (Kaufman and Koren, 2006; Bytnerowicz, *et*

al., 2007; IPCC, 2007). Aerosols exposure are associated with the occurrence of acute respiratory infections, lung cancer and chronic respiratory and cardiovascular diseases and increased mortality (Taus, *et al.*, 2008; Perrone, *et al.*, 2010; Gualtieri *et al.*, 2012). An increase in PM₁₀ by a concentration change of 10 µg/m³ can yield 1% increase in overall mortality and 3-6% increase in deaths associated with respiratory disease (Ostro *et al.*, 1999a and b; Kan *et al.*, 2010).

Atmospheric aerosols are a complex mixture of anthropogenic and natural origin.

Atmospheric aerosols size generally ranges from 0.01 to 100 μm . Based on size, aerosols can be classified into total suspended particles (TSP), PM_{10} , $\text{PM}_{2.5}$ and $\text{PM}_{1.0}$ particles with aerodynamic diameters of less than 100, 10, 2.5 and 1.0 μm , respectively. They can be emitted directly or be formed as secondary aerosol from the primary emissions through chemical reactions, such as gas to particulate formation, nucleation, coagulation and condensation that induce new particle formation (Samura, 2001; Kemp, 2002; Stortini, *et al.*, 2009; Byrd *et al.*, 2010; Im *et al.*, 2012). Emission from local pollution sources, special landform, poor atmospheric diffusion conditions and dust intrusions from upstream regions are important factors affecting atmospheric aerosols concentrations (Wang *et al.*, 1999; Wang *et al.*, 2000; Jiang, *et al.*, 2001; Liu, *et al.*, 2004; Ta, *et al.*, 2004). Variations of PM levels in response to changes in meteorological parameters were studied in different areas around the world (Gietl and Klemm, 2009; Akyuz and Cabuk, 2009; Bhaskar and Mehta, 2010; Galindo *et al.*, 2011; Dominick, *et al.*, 2012). Assuming the amount of PM emitted by anthropogenic sources is broadly constant in a given season and region, therefore seasonal variations in PM_{10} levels can be partially attributed to the effects of meteorological conditions (Giri, *et al.*, 2009). Wind speed, mixing height and relative humidity are thought to influence air pollutant concentrations (Gebhart *et al.*, 2001). Fast near surface winds are linked with high levels of particulate matter caused by resuspension of ground particles and long range transport of particulates between regions (Wise and Comrie, 2005; Gietl and Klemm, 2009). Stagnant wind conditions allow air pollutants to accumulate near the Earth's surface, resulting in elevated and localized concentrations of air pollutants (Chaloulakou, *et al.*, 2003).

There is a lack of information on PM_{10} concentrations in industrial areas of Jeddah. Previous studies on air pollution in Jeddah focused on urban areas (Khodeir, 2012, Alghamdi, *et al.*, 2014a,b,c; Hussein, *et al.*, 2014). Therefore, it is very important to evaluate the concentration levels of PM_{10} and factors affecting them in the atmosphere of Jeddah industrial area. This will help in setting a proper strategy to control the level of PM_{10} in the future. In the present study, data describing ambient PM_{10} concentrations, atmospheric temperature, relative humidity and wind speed were collected over one year from an ambient air quality station in the industrial area, south Jeddah city. These data were analysed to assess ambient PM_{10} levels, monthly and seasonal variations, and factors affecting them.

Materials and Methods

Study area

Jeddah is the second-largest city in Saudi Arabia and the largest in the province of Mecca. The city is surrounded by mountains in the north-east, east and south-east. It serves as a major hub for travel and commerce in the region. Because Jeddah is a primary transportation conduit for Muslim pilgrims visiting the Holy City of Makkah, local air quality is of particular concern. The southern part of Jeddah is the old city, which is densely populated, whereas the northern part of the city is new, well organized, and less populated. The annual growth rate of Jeddah's population in 2010 accounts around 3.7% (3.9%) with reference to 1992 (2004) census (Almazroui, *et al.*, 2013). Like almost everywhere else in the world, the Jeddah's environment and its citizen's health are affected by both mobile and stationary sources. Here, more than 1.40 million vehicles are running in the streets of Jeddah city (Khodeir, *et al.*, 2012). Vehicle fuels used in Jeddah are mainly unleaded

gasoline and diesel. South Jeddah, where the dust monitor was installed, is an urban area with industrial activities, narrow streets and relatively high traffic density. The stationary sources in the south Jeddah include an oil refinery, a power generation plant and several manufacturing industries. Regrettably, due to lack of awareness and proper regulations, these activities were accompanied by environmental degradation, and over the years the air quality has progressively deteriorated. Measurements of PM₁₀ and meteorology parameters were taken daily throughout January 2011 to December 2011 at a station located in an industrial area on the south side of Jeddah city.

The general climate of Jeddah city is warm and moderate in winter, with high temperature and high solar radiation in the summer season. Rainfall is generally sparse. The monthly variations of temperature, relative humidity and wind speeds during the period of study are graphically presented in Figure 1. From this figure, it can be found that, the monthly daily average temperature ranged from 23.80°C in January to 33.80°C in July, with an average of 28.40°C during the period of study. The average temperatures were 24.80°C in winter, 27.70°C in spring, 32.60°C in summer and 28.60°C in autumn. The monthly daily average relative humidity ranged from 49.80 % in July to 70.20% in October, with an average of 57.60% during the period of study. The average relative humidity was 63.40, 52.90, 54.00 and 60.10% in winter, spring, summer and autumn, respectively. The monthly daily average wind speeds ranged from 7.50 Km/h in January to 18.70 Km/h in March, with an average of 11.90 Km/h during the period of study. The average wind speeds were 9.70, 15.40, 12.10 and 10.20 Km/h in winter, spring, summer, and autumn, respectively.

Data and Equipment

PM₁₀ concentrations were monitored on an hourly basis using Environment S.A. MP101M beta gauges were used to measure particulate matter (lower detectable limit of 0.5 µg PM₁₀ for daily averages). The MP101 particulate matter beta gauge was calibrated monthly. Meteorological parameters (temperature, relative humidity, wind speed) measurements were taken using Vaisala WXT510 weather transmitter. The daily average concentrations of PM₁₀ were calculated at each gradient of the meteorological variables to investigate relationships between PM₁₀ and meteorological parameters.

Results and Discussion

Temporal trends of PM₁₀ concentrations

The temporal trends in daily average values of the PM₁₀ concentrations during the period of study are presented in Figure 2. Sharp daily PM₁₀ concentrations peaks were observed during the period of study. They were 488, 506, 458, 410, 381, 410, 443, 395 and 336 µg/m³. They occurred on 14 and 15 March, 16 April, 3 May, 23-25 July and 1 and 4 August, respectively. These elevated peaks might be attributed to the dust storm which occurs more frequently in the region during these periods. The impact of dust storms on the levels of PM₁₀ varies according to the source, frequency and strength of storm. The daily average concentrations ranged from 45 to 506 µg/m³ during the period of study.

Fig. 1. Monthly variation of temperature, relative humidity and wind speed.

Fig. 2. Daily means PM₁₀ concentrations during the period of study.

Monthly and seasonal variations of PM₁₀ concentration

The seasonal cycle characteristics of PM₁₀ are valuable for understanding important processes in atmospheric transport and chemistry. In this study, winter is defined as December-February, spring as March - May, summer as June - August, and autumn as September - November. The monthly variations of PM₁₀ concentrations during the period of study are graphically presented in Figures 3. The maximum monthly daily

average concentration of PM₁₀ was found in March, whereas the minimum concentration was observed in June. Monthly 24-hour average value varied from 83 (June) to 180 µg/m³ (March). The mean daily concentrations of PM₁₀ during the four seasons are graphically presented in Figure 4. From this figure, it can be seen that the highest concentration of PM₁₀ was found in Spring, whereas the lowest levels were detected in Autumn. The mean daily concentrations of PM₁₀ were 120, 144, 116 and 89 µg/m³ in winter, spring, summer and autumn, respectively. Jeddah city is exposed to many bouts of dust storm events during the year, especially during winter and spring seasons, so the local particulate emission solely in the study area cannot explain the highest levels of PM₁₀ concentrations that appeared in spring season. A large input of dust from the upstream regions during sand-dust events might be the main reason for the increased atmospheric levels of PM₁₀ concentration in spring. Low concentrations of PM₁₀ in autumn might be due to better diffusion conditions and little occurrence of dust events.

Fig. 3. Monthly variation of PM₁₀ concentrations during the period of study.

The annual average concentrations of PM₁₀ in the present study (Figure 4) was clearly much higher than the World Health Organization (WHO) PM₁₀ annual average (20 µg/m³) (WHO, 2006). The frequency percentage distribution of the 24-h average PM₁₀ concentrations is graphically presented in Figure 5. The WHO air quality standards for 24-h PM₁₀ is 50 µg/m³. Almost all the mean 24-h concentration of PM₁₀ during summer, autumn, winter, spring and the whole year, respectively, (Figure 5), exceeded the WHO air quality standards for maximum 24-h concentration.

Weekday/weekend variations of PM₁₀ concentration

The seasonal variations of weekday/weekend PM₁₀ concentrations during the period of study is graphically presented in Figure 6. From this figure, it can be seen that the average concentrations of PM₁₀ were relatively higher in weekdays than weekends during the different seasons. They averaged 123, 150, 121 and 93 µg/m³ in weekdays and 104, 110, 86, and 72 µg/m³ in weekends during winter, spring, summer and autumn seasons, respectively. The weekdays/weekends concentration ratios were 1.18 (winter), 1.36 (spring), 1.41 (summer) and 1.29 (autumn). The annual PM₁₀ concentrations were 123 µg/m³ in weekdays and 93 µg/m³ in weekends, with weekdays/weekends concentration ratio of 1.32. The lower PM₁₀ in weekends than weekdays may be attributed to the decrease of traffic density due to the official days-off of government institutions, schools and colleges. This did not only cause low exhaust particulate emission, but also decreased the formation of secondary aerosol and reduced emissions generated from tyre wears and re-suspension of street dust in weekends. This is in agreement with Latha and Highwood (2006), Lough, *et al.* (2006),

Lonati, *et al.* (2006), Karar *et al.* (2006), Khoder and Hassan (2008), Kulshrestha, *et al.* (2009) and Hassan *et al.* (2013) who have attributed the decrease in aerosols concentration on weekend days to the decrease in traffic density.

Fig. 4. Seasonal and annual variation of PM₁₀ concentrations during the period of study.

Fig. 5. Frequency percentage distribution of daily PM₁₀ concentrations.

Fig. 6. Seasonal and annual variation of weekdays and weekend PM₁₀ concentrations during the period of study.

Dust storm/non-dust storm variations of PM₁₀ concentration

The average PM₁₀ concentrations in dust storm (DS) and non-dust storm (non-DS) days during the period of study is graphically presented in Figure 7. The mean values were 101 µg/m³ in non-DS and 317 µg/m³ in DS. The DS/non-DS concentration ratio was 3.14. This result indicates that a large input of dust from the upstream regions during sand-dust events is the main reason for the high PM₁₀ concentration in the study area. Dust concentrations in DS periods were significantly higher than those in non-DS periods (Mori *et al.*, 2003; Chen *et al.*, 2004; Lee *et al.*, 2009; Hong *et al.*, 2010; Bian *et al.*, 2011; Li *et al.*, 2011; Wang *et al.*, 2011; Zhao *et al.*, 2011; Tsai *et al.*, 2012; Chuang *et al.*, 2013). In the present study, the average concentrations of PM₁₀ in non-DS and DS were clearly much higher than the recommended World Health Organization (WHO) PM₁₀ concentration (50 µg/m³ for 24 h) (WHO, 2006).

Fig. 7. Mean PM₁₀ concentrations in dust storm and non-dust storm days during the period of study.

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العوامل التي تؤثر على مستويات الأتربة العالقة ذات الأحجام الأقل من ١٠ ميكرون في الغلاف الجوي للمنطقة الصناعية بجدة، المملكة العربية السعودية

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المستخلص. تم تحليل وتقييم البيانات التي تصف تركيزات الأتربة العالقة ذات الأحجام الأقل من ١٠ ميكرون (PM₁₀) وبعض البيانات الخاصة بالأرصاد الجوية (درجة الحرارة، والرطوبة النسبية، وسرعة الرياح) خلال الفترة من يناير ٢٠١١ إلى ديسمبر ٢٠١١م. تم جمع البيانات من محطة جودة الهواء المحيط في المنطقة الصناعية بجنوب جدة. وجرى تقييم التغيرات الشهرية والموسمية لتركيزات الأتربة العالقة ذات الأحجام الأقل من ١٠ ميكرون (PM₁₀) وتقييم العوامل التي تؤثر عليها. وجد أن متوسط التركيزات اليومية للـ PM₁₀ تراوحت بين ٤٥-٥٠٦ ميكروجرام للمتر المكعب هواء مع قيمة متوسطه ١١٩ ميكروجرام للمتر المكعب هواء خلال فترة الدراسة. وجد أن أغلب متوسطات التركيزات اليومية للـ PM₁₀ خلال فترة الدراسة تجاوزت معايير جودة الهواء لمنظمة الصحة العالمية لأقصى تركيز للـ ٢٤ ساعة. وجد إن أعلى تركيزات للـ PM₁₀ كانت خلال فصل الربيع بينما أقل المستويات كانت في فصل الخريف. كانت متوسطات التركيز للـ PM₁₀ ١٢٠، ١٤٤، ١١٦، و ٨٩ ميكروجرام للمتر المكعب هواء في الشتاء والربيع والصيف والخريف على التوالي. كانت تركيزات الـ PM₁₀ أعلى نسبياً خلال أيام العمل عنها خلال أيام العطلات خلال الفصول المختلفة. وكانت نسب متوسط تركيز الأتربة في أيام العمل إلى أيام العطلات هي ١,١٨ (الشتاء)، ١,٣٦ (الربيع)، ١,٤١ (الصيف)، و ١,٢٩ (الخريف)، و ١,٣٢ (السنوي)، وقد كانت تركيزات الـ PM₁₀ أعلى في أيام العاصفة الترابية مقارنة بالأيام بدون عاصفة ترابية. وكانت نسبة التركيز أثناء العاصفة الترابية إلى التركيز بدون عاصفة ترابية هي ٣,١٤. **الكلمات الدالة:** الأتربة العالقة ذات الأحجام الأقل من ١٠ ميكرون، التغيرات الزمنية والموسمية، أيام العمل/أيام العطلات، العواصف الترابية، المنطقة الصناعية، جدة.