Accumulation and coarse mode aerosol concentrations and carbonaceous contents in the urban background atmosphere in Amman, Jordan

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Abstract

In this study, we analyzed the concentrations of accumulation and coarse modes measured during November 2013–July 2017 at an urban background site in Amman, Jordan. The concentrations showed distinct seasonal variations with high concentrations with a monthly average higher than 100 cm^{-3} and 1.5 cm^{-3} , respectively, for accumulation and coarse modes during the winter and low concentrations with a monthly average less than 40 cm^{-3} and $1\text{--}1.5 \text{ cm}^{-3}$, respectively, for accumulation and coarse modes during the summer. Sand and dust storms (SDS) affected the coarse mode during the early spring whereas local dust resuspension affected them during the autumn. The gravimetric analysis confirmed the seasonal variation of the calculated particulate mass concentration but suggested that the assumption of spherical particles and unit density is not always proper. The ATR-FTIR analysis of selected filters revealed that aerosols in the background atmosphere of Amman are a mixture of locally emitted (fossil fuel combustion) and local/regional dust. Based on the 24-h average of the calculated PM_{10} , the pollution standard index (PSI) revealed that about 81% of the days were either good or moderate air quality conditions. About 71% of the days were below the 24-h PM_{10} limit value according to the Jordanian air quality standards ($120 \mu\text{g m}^{-3}$).

Keywords Seasonal · Long-term · Pollution standard index (PSI) · Gravimetric analysis · ATR-FTIR

Introduction

The mass concentration of the aerosol population is mostly composed of the accumulation and the coarse modes. Although the coarse mode aerosols (diameter $2.5\text{--}10 \mu\text{m}$) have high settling velocity, they can be transported far away from their source origin (e.g., Saharan dust episodes). When

compared to the whole aerosol population, those within the accumulation mode (diameter $0.1\text{--}1 \mu\text{m}$) have the lowest deposition velocity; and thus, they survive for a long time and they can be transported within large spatial scale. Dust aerosols are not only confined within the coarse mode; a small fraction of airborne dust aerosols can be also found in the fine fraction with diameters larger than $0.1 \mu\text{m}$ (i.e., accumulation mode). The accumulation mode also consists of aerosols formed via direct emissions (i.e., primary aerosol) or during transformation mechanisms of ultrafine particles such as condensation and coagulation (e.g., Seinfeld and Pandis 2006).

Jordan, which has a central geographical location within the Middle East and North Africa (MENA), experiences regional dust episodes as well as local dust resuspension events. This imposes a serious threat because of continuous exposure to elevated PM_{10} concentrations. In general, most of the aerosol research in the MENA region have been focused on the PM and some chemical characterization (e.g., Hamad et al. 2015; Gherboudj and Ghedira 2014; Alghamdi et al. 2014a, b, 2015; Abdeen et al. 2014; Hussein et al. 2014; Hassan et al. 2013; Boman et al. 2013; Daher et al. 2013; Engelbrecht and

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Jayanty 2013; Habeebullah 2013; Khodeir et al. 2012; Rushdi et al. 2013; Shaltout et al. 2013; Waked et al. 2013a; Kouyoumdjian and Saliba 2006; El-Araby et al. 2011; Hussein et al. 2011; Saliba et al. 2010). Recently, long-range transport and sand dust storms/transport have been considered as a priority of the aerosol research in the MENA (e.g., Al-Dousari et al. 2017; Basha et al. 2015; Doronzo et al. 2015; Alam et al. 2014; Jaafar et al. 2014; Saeed et al. 2014; Dada et al. 2013; El-Askary et al. 2009; El-Askary and Kafatos 2008; Reid et al. 2008; Saliba et al. 2007; Satheesh et al. 2006; Daum et al. 1993). However, the particle number concentrations, particle number size distributions, and long-term data-base analysis have not been given enough attention in the MENA region (e.g., Hussein et al. 2016, 2017, 2011; Hussein and Betar 2017; Lihavainen et al. 2017; Moustafa et al. 2015; Munir et al. 2013a, b; Waked et al. 2013b; Tadros et al. 1999). Furthermore, the atmospheric research community in Jordan is very small and their research output has not been very active in characterizing the chemical and physical properties of aerosols in Jordan (e.g., Hussein et al. 2011, 2017; Hussein and Betar 2017; Roumie et al. 2016; Abdeen et al. 2014; Gharaibeh et al. 2010; Hamasha and Arnott 2010; Schneidmesser et al. 2010; Abu-Allaban et al. 2006; Al-Momani et al. 2005).

The main objective of this study is to present, for the first time, the size-fractionated particle number and mass concentrations of the accumulation and coarse modes in Amman

during a long-term period (November 2013–July 2017). We focused on the temporal variation (hourly, daily, monthly, and seasonal) of two particle size-fractions: accumulation mode (0.3–1 μm) and coarse mode (1–10 μm). We also assessed the pollution standard index (PSI) based on the 24-h average of the calculated PM_{10} . Additionally, we perform gravimetric analysis and chemical characterization for the carbonaceous aerosols. According to our knowledge, the carbonaceous contents of aerosols have never been evaluated in the urban atmosphere in Jordan.

Materials and methods

Site description

The University of Jordan campus [32.0129N, 35.8738E] is in the northern part of Amman, Jordan. It is about 10 km from the city center (Fig. 1a). The campus is surrounded by a populated residential area with small roads network. One of the main highways goes parallel to the western side of the campus. The main sources of air pollution at this site are traffic emissions and small-scale combustion processes from restaurants on and around the university campus. The Department of Physics, where the aerosol measurement took place, is in the middle of the campus (Fig. 1b).

Fig. 1 **a** A Map of Amman showing the campus of the University of Jordan (shaded) and **b** the campus of the University of Jordan

Aerosol measurement

The aerosol measurement was performed during November 2013–July 2017 using an Optical Particle Sizer (OPS, TSI model 3330). The OPS was placed inside a laboratory in the second floor of the Department of Physics. The aerosol inlet was led through the window (height ~10 m from the ground level). The instrument was calibrated prior to the measurement campaign in 2013 and compared with a calibrated OPS (TSI model 3330) in June 2016. The comparison between both instruments showed difference less than 5% in the total number concentrations.

The OPS 3330 continuously measured the particle number size distribution (optical diameter 0.3–10 μm) with the setting as TSI default particle size bins, which were 13 equally sized bins based on a lognormal scale. The dead-time correction was applied in the OPS operation. Sampling time resolution was 5 min with a flow rate ~1 L/min. A diffusion drier was used in the aerosol tubing in order to sample the dry aerosol particle number size distribution. The penetration efficiency through the tubing and the diffusion drier was determined experimentally, where the penetration efficiency was ~93% for 0.3 μm and ~40% for 10 μm . The aerosol data-set was corrected for losses in the tubing and the diffusion drier.

We calculated the particle number concentration (cm^{-3}) and particle mass concentration ($\mu\text{g}/\text{m}^3$) in two size fractions:

- accumulation mode (diameter 0.3–1 μm)
- coarse mode (diameter 1–10 μm)

That was done by integrating the measured particle number size distribution over the specified particle diameter range.

$$PN_{D_{p2}-D_{p1}} = \int_{D_{p1}}^{D_{p2}} n_N^0 d\log_{10}(D_p) \quad (1)$$

where $n_N^0 = dN/d\log_{10}(D_p)$ is the measured particle number size distribution and D_p is the particle diameter.

The particle mass concentrations can be also calculated by integrating the particle number size distribution as follows.

$$PM_{D_{p2}-D_{p1}} = \int_{D_{p1}}^{D_{p2}} \frac{\pi}{6} D_p^3 \rho_p n_N^0 d\log_{10}(D_p) \quad (2)$$

where ρ_p is the particle density. Here, we assumed spherical particles and particle density 1 g/cm^3 .

The OPS was equipped with a standard 37 mm diameter cascade to collect aerosols during sampling on filter media. We occasionally used this feature of the OPS by using Teflon filters (TEFLO, 2.0 μm and 37 mm PTFE Membrane with ring). Therefore, we were able to perform aerosol gravimetric analysis (Mettler Toledo micro balance UMT 2, Mettler Toledo electrostatic neutralizer, conditioning chamber, and T

and RH control unit) as well as some chemical analysis based on Attenuated Reflection Fourier Transform Infrared Spectrometer (ATR-FTIR; Thermo Nicolet Nexus 670). The gravimetric analysis included:

- (1) pre-conditioning and pre-weighing of the empty filters at ~45% relative humidity and 23 $^{\circ}\text{C}$ temperature.
- (2) aerosol collection on the filter for at least 20 days.
- (3) post-weighing of the loaded filters at the same conditions used during pre-weighing.

The weighing was performed three times with a microbalance (6 digits). The average weight was reported for each filter. The particulate matter (PM) concentration collected on the filters was then calculated according to:

$$PM = \frac{M - M_0}{Q \times \Delta t} \quad (3)$$

where M and M_0 are the filter weight before and after sampling (i.e., pre-weight and post-weight), Q [$\text{m}^3 \text{h}^{-1}$] is the flow rate during aerosol sampling, and Δt [h] is the sampling duration. According to the OPS setup, Q was 1 lpm.

Weather conditions

The weather conditions were measured on the roof top of the Department of Physics since February 2015. The measurement was conducted with a weather station (Weather Station WH-1080, Clas Ohlson: Art. no. 36-3242). The time resolution of the measurement was 5 min.

The weather station consists of an automatic data logger, which is controlled by its own software installed on a personal computer and sensors, which are connected wirelessly with the data logger. The sensors measure ambient temperature, absolute pressure, relative humidity, wind speed and direction, and precipitation. According to the specifications of the weather station, the measurement range of each parameter is as follows:

- ambient temperature –40–65 $^{\circ}\text{C}$ (resolution 0.1 $^{\circ}\text{C}$)
- absolute pressure 918.7–1079.9 hPa (resolution 0.3 hPa)
- relative humidity 10–99% (resolution 1%)
- wind speed 1–160 km/h
- wind direction 16 equal divisions
- precipitation 0–9999 mm (resolution 0.3 mm below 1000 mm and 1 mm over 1000 mm)

The weather station software provides additional weather parameters: relative pressure, gust, dew point, wind chill, and rainfall (hourly, daily, weekly, monthly, and total). These additional weather parameters were not considered in the current study. During February 2015–July 2017 (based on the hourly

averages; Fig. 2), the temperature varied between -3.7 and 39 °C with an overall average 17.8 ± 8.4 °C and the absolute pressure varied between 666 and 684 mmHg with an overall average 675 ± 3 mmHg. The overall average value of the relative humidity was $58 \pm 26\%$ whereas that of the wind speed 5.4 ± 3.6 km/h (maximum value was about 22 km/h). The prevailing wind direction varied evenly from all directions at this site. The accumulated rain amount during February 2015–July 2017 was about 1114 mm.

Data handling

Both the aerosol data-base and the weather data-base were quality checked against possible instrument malfunctions; suspicious data was eliminated if correction was not possible. Before the analysis, we processed the aerosol and weather data-bases by calculating hourly averages. The hourly average data-base was then used to calculate daily and monthly statistical analysis (average, standard deviation, minimum, 5%, 25%, median, 75%, 95%, and maximum).

Results and discussion

Seasonal and diurnal variations

The particle number concentrations of the accumulation mode showed a clear seasonal variation (Fig. 3a). Based on the monthly average and median (Fig. 4a), the accumulation mode had its maximum concentration during December and January, which often exceeded 100 cm^{-3} . The accumulation mode concentrations decreased from over 100 cm^{-3} in January to slightly less than 40 cm^{-3} in April during which was the minimum monthly average throughout the year. The concentrations started to increase reaching a monthly average of about 90 cm^{-3} during May–August and then slightly dropped down in September but continued to increase after that until December.

We have to bear in mind that our experimental setup did not cover the full particle diameter range of the accumulation mode, which is typically assumed $0.1\text{--}1 \text{ }\mu\text{m}$ (e.g., Wu et al. 2008; Hussein et al. 2004; Birmili et al. 2001). Usually, the particle number concentration fraction within the diameter

Fig. 2 Time series (hourly, daily, and monthly average) of the weather conditions **a** temperature, **b** relative humidity, **c** pressure, **d** wind speed, and **e** accumulated rain (since February 2015)

Fig. 3 Time series (hourly, daily, and monthly average) of the **a** number concentration of the accumulation mode size-fraction and **b** number concentration of the coarse mode

range $0.3\text{--}1\text{ }\mu\text{m}$ is $\sim 5\%$ of the whole accumulation mode. Therefore, we expect that the full range of the accumulation mode particle number concentration at our site would be

Fig. 4 Monthly averaged particle number concentrations for the **a** accumulation mode and **b** the coarse mode. The square represents the average, the box represents the median value (red dash) and quartiles, the whiskers are 5% and 95% percentiles

between 800 cm^{-3} in the summer and 2000 cm^{-3} in the winter. The accumulation mode particle number concentration is within what can be found in European urban environments and West Africa (e.g., Hama et al. 2017; von Bismarck-Osten et al. 2013; Aranda et al. 2015; Sunnu et al. 2008; Charron et al. 2007; Hussein et al. 2004; Wehner and Wiedensohler 2003; Birmili et al. 2001). Compared to highly populated cities in Eastern Asia (e.g., Yu et al. 2017; Cheung et al. 2016; Hu et al. 2016; Sun et al. 2016; Zhang et al. 2016; Wang et al. 2011; Xu et al. 2011; Wu et al. 2008), the accumulation mode concentration found in this study is less by a factor of 2–5.

The particle number concentrations of the coarse mode also showed a clear seasonal variation in this study (Fig. 3b), which was slightly different than that observed for the accumulation mode (Fig. 3a). Based on the monthly median values (Fig. 4b), the concentrations were the highest during November–January, when the monthly median exceeded 1.5 cm^{-3} . The monthly median leveled between 1 and 1.5 cm^{-3} during March–October. These observed concentrations of the coarse mode in this study are higher than what is usually found in Europe (e.g., Preißler et al. 2011; Marinoni et al. 2008) but comparable to middle Asian conditions (e.g., Wang et al. 2011). In some European cold regions (such as Scandinavian countries) and during early spring, they experience local road dust resuspension due to the use of winter tires that wear the road surface (e.g., Hussein et al. 2008; Omstedt et al. 2005). Apparently, Jordan lies within the region, where potential sand dust storm (SDS) episodes occur frequently and intensively (e.g., Al-Dousari et al. 2017; Doronzo et al. 2015; Reid et al. 2003), in addition of being semi-arid, which pose of a high potential of local dust resuspension in addition to SDS (e.g., Lihavainen et al. 2016). For example, Doronzo et al.

(2015) provided a map, which was modified after Engelstaedter et al. (2006), showing the main regions of potential sources of SDS as North Africa and East Asia (e.g., Arabian Peninsula, Iraq, Syria, Iran, Afghanistan, etc).

Interestingly, the monthly average values of the coarse mode number concentrations tended to be close to or higher than the 75% value during the spring and autumn (Fig. 4b). One reason for that is the high probability of dust episodes in the spring season and another reason is the extremely dry conditions during the autumn season that enhances resuspension of local dust. Besides that, the number concentration seasonal variation (with a maximum in the winter time) of both the accumulation and coarse modes suggests that a significant fraction of these aerosols come from local sources; this is supported by the fact that high concentrations were observed during the winter time. A closer look at the diurnal variation also supports this hypothesis. For instance, the daily pattern showed two main peaks: the first one represents the morning traffic rush hours whereas the other peak represents the afternoon and evening traffic activities (Fig. 5). The day-time median number concentrations were as high as 60 cm^{-3} for accumulation mode and about 1.6 cm^{-3} for the coarse mode. Between 03:00 and 06:00, the concentrations were at their minimum levels for both accumulation mode ($\sim 45 \text{ cm}^{-3}$) and coarse mode ($\sim 1 \text{ cm}^{-3}$). The minimum traffic activities in the city usually occur during this time-period of the day.

Engelstaedter et al. (2006) showed that satellite and observational data revealed that North African dust emissions follow a strong annual cycle, which is most likely affecting the seasonal cycle of accumulation and coarse modes in the East Mediterranean. For instance, our observations here with respect to seasonal variation of the measured accumulation and coarse mode concentrations agrees well with the annual cycle of dust occurrence in the east Mediterranean (Yuval et al. 2015). In other regions of the world, the coarse mode as well

as the accumulation mode fraction in the diameter range $0.3\text{--}1 \mu\text{m}$ are often associated with airborne dust (e.g., Zhang et al. 2006). The seasonal cycle in the accumulation and coarse mode concentrations also has been observed in middle Europe (e.g., Marinoni et al. 2008). The seasonal variation of both accumulation and coarse modes is expected as a result of the source seasonal variability. For example, in cold countries, where they extensively use winter tires, the road dust is built up during the winter time and become resuspendable in the early spring (e.g., Omstedt et al. 2005). Traffic activity as a source of coarse particle was also verified by Barmpadimos et al. (2011) in middle European urban conditions.

Gravimetric and black carbon analysis

The gravimetric sampling was not performed continuously. Figure 6 shows the available results for the particulate mass (PM) concentrations obtained from the gravimetric analysis. The gravimetric results confirmed the seasonal variation of the particulate matter concentrations; high concentrations during the winter and low concentrations during the summer. The gravimetric results were also compared to the mass concentration that was calculated from the measured particle number size distribution by assuming spherical particles and unit particle density (i.e., $\rho_p = 1 \text{ g cm}^{-3}$). Most of the time, the calculated mass concentrations were lower than those obtained with the gravimetric analysis. This is expected because of several reasons: (1) the calculated PM concentrations were limited to the measured particle diameter range $0.3\text{--}10 \mu\text{m}$, (2) the calculation assumed spherical particles, and (3) the density of the particles was assumed unit density. In practice, the collected particulate matter on the filters (i.e., gravimetric analysis) also contains aerosols smaller than $0.3 \mu\text{m}$. Aerosols in the micron size fraction do not necessarily be spherical and their density is higher than $\rho_p = 1 \text{ g cm}^{-3}$. Nevertheless, the available data

Fig. 5 Daily pattern calculated over the whole measurement period of the particle number concentrations for **a** the accumulation mode and **b** coarse mode. The square represents the median whereas the box represents the quartiles

Fig. 6 Particulate matter (PM) concentrations obtained from the gravimetric analysis and compared with the mass calculated from the measured particle number size distribution (assuming unit density). The width of the gravimetric analysis histogram corresponds to the sampling period. The vertical and horizontal bars of the calculated mass correspond to the standard error and sampling period, respectively

from both gravimetric and optical measurement in the same unit (the OPS) is a useful setup to confirm the reliability of the aerosol measurement.

We selected some filters to be taken to the ATR-FTIR analysis. The selection was based on sufficient deposited amount on the filter. That required continuous sampling of more than 15 days with our OPS setup, which had 1 lpm sampling flow. In fact, the deposition was not fully uniform, but we believe this should not affect the FTIR analysis (e.g., Miller et al. 2013). According to the ATR-FTIR analysis, the spectra showed three interesting major signals (Fig. 7) for carbon containing compounds that are emitted from fossil fuel combustion such as traffic tailpipe emissions (e.g., Siciliano et al. 2018; Popovicheva et al. 2017; Shaltout et al. 2016; Agudelo-Castañeda et al. 2015; Popovicheva et al. 2015; Jiang et al. 2011). The first signal (wave number 800–1100 cm^{-1} ; mass fraction 37.1–45.6%) represents polycyclic aromatic hydrocarbon compounds that contain functional groups such as sulfur,

hydroxyl, or ester. The second signal (wave number 1300–1550 cm^{-1} ; mass fraction 11.3–17.4%) corresponds to carbon compounds that contain nitro functional groups accompanied with sulfones compounds. The third signal (wave number 2250–2400 cm^{-1} ; mass fraction 4.2–5.3%) corresponds to carbon compounds that contain amines. The remaining mass fraction was unknown due to limitation of our methods. Most likely, this fraction includes aerosols from regional dust transport and/or local resuspension from building construction activities that uses different types of sand and stones (e.g., Anil et al. 2014; Cuccia et al. 2011; Coury and Dillner 2009; Maria et al. 2002), which is common in Amman region nowadays.

Daily air quality–Pollution standards index

The air quality conditions with respect to dust loading in the atmosphere can be evaluated based on our long-term measurements of the accumulation and the coarse modes presented in

Fig. 7 Attenuated Reflection Fourier Transform Infrared Spectrometer (ATR-FTIR) spectra for the filter samples collected during aerosol measurement of the particle number size distributions with the Optical Particle Sizer (OPS). The time periods of the sampling are also indicated in the legend

this study. For that purpose, we calculated the pollution standards index (PSI) based on the 24-h average of the calculated PM_{10} , which was calculated by assuming spherical particles and density close to dust particle; $\rho_p = 2.5 \text{ g cm}^{-3}$ (Fig. 8a). We have to keep in mind here that most of the aerosol particulate mass is confined within particles larger than $0.1 \text{ }\mu\text{m}$ in diameter. Therefore, the calculated particulate mass with particle density $\sim 2.5 \text{ g cm}^{-3}$ is expected to be a good indication for the PM_{10} .

It is interesting to mention here that the temporal variation of the calculated PM_{10} was similar to what was observed for the coarse mode. The maximum monthly average was about $375 \text{ }\mu\text{g m}^{-3}$, which was observed during December 2013 right after heavy snow fall. The minimum monthly average PM_{10} was about $35 \text{ }\mu\text{g m}^{-3}$, which was observed during June 2017. During the measurement period (November 2013–July 2017), we found 300 days when the PM_{10} exceeded the Jordanian 24-h PM_{10} concentration limit value ($120 \text{ }\mu\text{g/m}^3$). Most of these days were not during the summer time.

As for the pollution standards index (PSI), we can evaluate it based on the 24-h average of the calculated PM_{10} . We used the breakpoints as defined by the US-EPA guideline for reporting of daily air quality–pollutant standards index (draft: December 1998). According to this guideline, hazardous air quality conditions are reported when the PSI value exceeds 301. When the PSI is in the range 201–300, the air quality is considered very unhealthy whereas the range 151–200 is considered unhealthy. The range 101–150 is considered unhealthy for sensitive groups. Moderate and good air quality conditions are reported for PSI ranges 51–100 and below 0–50, respectively. According to this criterion, the calculated PSI in this study indicated 23 days being hazardous, 16 days were very unhealthy, 39 days were unhealthy, and 126 days were

unhealthy for sensitive groups (Fig. 8b). In total, these were 204 days. The total number of moderate air quality conditions was 425 whereas good air quality conditions were 426.

This simple PSI analysis means that about 81% of the measurement days during November 2013–July 2017 were either good or moderate air quality conditions. This should be compared to the number of days when the 24-h PM_{10} average value did not exceed the Jordanian air quality standards. As mentioned in the previous section, these were 300 days, which corresponds to about 71%.

Conclusion

In this study, we presented accumulation mode ($0.3\text{--}1 \text{ }\mu\text{m}$) and coarse mode ($1\text{--}10 \text{ }\mu\text{m}$) concentrations measured during November 2013–July 2017 at an urban background site in Amman, Jordan. This is the longest time-series of aerosol concentrations to be reported in Jordan. We investigated the temporal variation with different time/scales: hourly, daily, monthly, and seasonal. As an interesting part of the analysis, we assessed the pollution standards index (PSI) based on the 24-h average of the calculated PM_{10} .

The analysis revealed distinguished seasonal variation for the accumulation and coarse mode concentrations. The high concentrations were, generally, observed during the winter. The monthly average of the accumulation mode concentrations was often higher than 100 cm^{-3} during the winter and less than 40 cm^{-3} during late spring and summer. The seasonal variation of coarse mode concentrations was slightly different than that of the accumulation mode. The monthly average of the coarse mode concentrations was observed higher than 1.5 cm^{-3} during the winter and early spring and in the range

Fig. 8 Daily air quality–pollutant standards index (PSI) calculated for total particulate mass concentration (represented as PM_{10} by assuming spherical particles and $\rho_p = 2.5 \text{ g/cm}^3$). The PSI calculation was based on the PM_{10} breakpoints as defined in the US-EPA guideline for reporting of daily air quality–pollutant standards index (draft: December 1998)

1–1.5 cm⁻³ throughout the summer. The reasons for high concentrations during the spring were due to sand and dust storms (SDS) as well as local dust resuspension from arid lands and due to traffic activities.

The gravimetric analysis confirmed the seasonal variation of the calculated particulate mass concentration but suggested that the assumption of spherical particles and unit density is not always proper. The maximum monthly average of the calculated mass concentration was ~375 µg m⁻³, which was observed during the winter, whereas the minimum monthly average concentration was ~35 µg m⁻³, which was observed during the summer. Most of these days were not during the summer time. The ATR-FTIR analysis of selected filters revealed that aerosols in the background atmosphere of Amman are a mixture of locally emitted (fossil fuel combustion) and local/regional dust.

According to PSI calculations during the measurement period, 23 days were hazardous, 16 days were very unhealthy, 39 days were unhealthy, and 126 days were unhealthy for sensitive groups. The total number of moderate air quality conditions was 425 whereas good air quality conditions were 426. About 81% of the measurement days during were either good or moderate air quality conditions. About 71% of the measurement days were below the 24-h PM₁₀ limit value according to the Jordanian air quality standards (120 µg m⁻³).

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