

Particulate matter and bacteria characteristics of the Middle East Dust (MED) storms over Ahvaz, Iran

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Abstract The Middle East Dust storms have greatly affected the south and west parts of Iran during the last decade. The main purpose of this study was to examine and compare culturable airborne bacteria concentration in particulate matter (PM) during normal, semi-dust, and dust event days in different places and seasons in Ahvaz from November 2011 to May 2012. Sampling was performed every 6 days and on dust event days at different sampling stations. The overall mean concentrations of PM₁₀, PM_{2.5}, and PM₁ for the

entire study period were 598.92, 114.8, and 34.5 µg/m³, respectively. The PM concentrations during the dust event days were much higher than normal and semi-dust event days. The highest mean PM concentrations were observed in March 2011. The low PM_{2.5}/PM₁₀ ratios indicate that these PM are mostly originating from natural sources such as dust storms. The overall mean concentration of total bacteria during the study period was 620.6 CFU/m³. The greatest bacterial concentrations were observed during dust event days and at areas with high traffic and more human activities compared with normal days and greener areas. The percentage of gram-positive bacteria was significantly higher than that during the study period (89 vs 11 %). During this study, 26 genera of culturable bacteria were identified from all the sampling stations. The most dominant genera in all sampling stations were *Streptomyces*, *Bacillus*, *Kocuria*, *Corynebacterium*, and *Paenibacillus*. The results also showed that there were positive correlations between PM and bacterial concentrations during the study period ($p < 0.05$).

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1 Introduction

Air pollutants, especially ambient particulate matter (PM) have been associated with both short-term and

long-term adverse health effects including respiratory and cardiopulmonary diseases. The American Cancer Society Study, for example, carried out a large cohort study with 552,000 participants who were followed up for a period of 16 years. The study reported that each $10 \mu\text{g m}^{-3}$ increment in $\text{PM}_{2.5}$ led to an increase of cardiovascular mortality of 8–18 %. For these reasons, ambient PM is considered to be an important indicator of the outdoor air quality (Fromme et al. 2008; Geller et al. 2002; Niu et al. 2010). The natural events that produce substantial PM concentrations, and usually occurring in arid, semi-arid, or desert areas and primarily resulting from low vegetation cover and strong surface winds, are defined as dust events. Dust events carry large amounts of PM to the regional and global atmosphere (Shahsavani et al. 2012b). The largest sources of dust in the earth's atmosphere are natural deserts and semi-arid areas, which are located mainly in Northern Hemisphere, (the Sahara and Sahel regions of North Africa, the Gobi, Taklamakan, and Badain Jaran deserts of Asia). These deserts release approximately 2 billion metric tons of dust into the earth's atmosphere annually. Fifty to seventy percent of this amount is believed to originate from the Sahara and Sahel (Griffin and Kellogg 2004; Moulin et al. 1997; Shahsavani et al. 2012b). Dust events can produce a large-scale transport of bioaerosols, and thereby affect downwind population and ecosystems. Biological material or bioaerosol in the earth's atmosphere exist in the forms of pollen, bacteria, fungal spores, viruses, and fragments from plants, animals, or any living organism. Biological materials comprise a significant fraction of the ambient PM. For example, in remote locations about 28 percent by volume of PM contains biological materials (Maki et al. 2008; Raisi et al. 2013; Zhu et al. 2003). The origin of bacterial aerosols is natural and anthropogenic sources, such as vegetables and plants, soil, water bodies, animal feeding, fermentation process, sewage sludge, and agricultural activities (Wang et al. 2010). Due to their abundant sources and ubiquitous presence in the environments, elevated concentrations of bacteria are associated with increasing probability of epidemics, allergic respiratory symptoms, deterioration of medicine, cosmetics and food contamination, and also imposition of direct impacts on human health and economy (Fang et al. 2007; Ho et al. 2005). The two crucial parameters that have an effect on survival and distribution of bacterial aerosols are biological

factors and meteorological conditions (Fang et al. 2007).

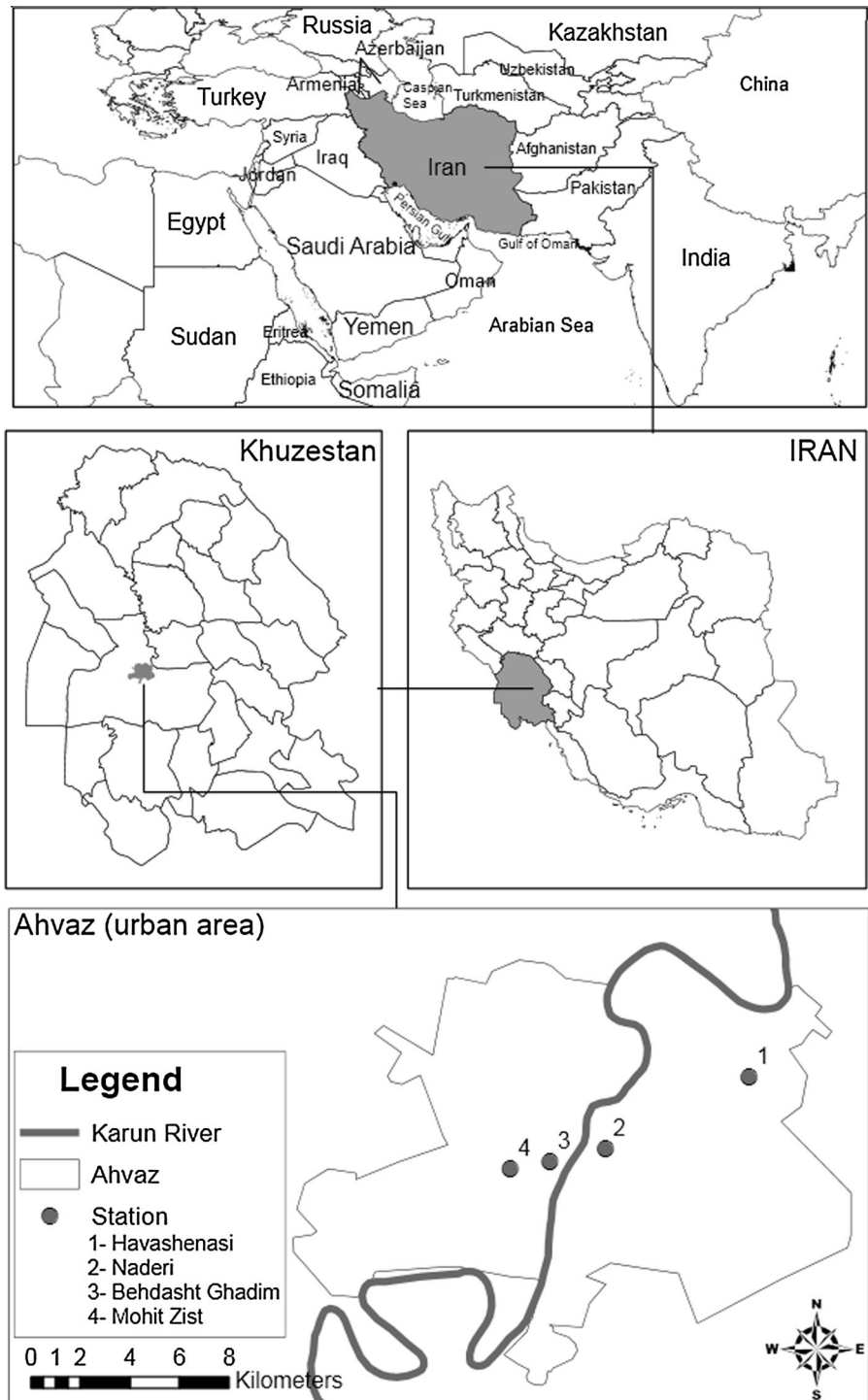
According to the previous studies, the other major sources of desert dust are believed to be the Arabian Peninsula, Kuwait, Iraq, and parts of Iran, which contribute significantly to the total transport of dust particles in the Middle East (Léon and Legrand 2003; Shahsavani et al. 2012a). Since 2004, Ahvaz, the biggest city in the southwest of Iran, has been experiencing major desert dust events originating from the sources mentioned. The frequencies of dust storms were 29, 33, 55, 45, and 17 in 2005, 2006, 2007, 2008, and 2009, respectively. The closure of industrial and educational centers, loss of agricultural crops, the decrease in visibility, flight cancellations, and increases in hospital admission cases are some examples of economical, environmental, and hygienic problems caused by these major dust events (Goudie and Middleton 2006; Shahsavani et al. 2012b; Soleimani et al. 2013). Despite its importance, to the best of our knowledge, no study has ever investigated the bacterial concentration of PM during normal and dust event days in Ahvaz and the adjacent countries, which are increasingly experiencing dust storms. Therefore, the present study aimed to measure bacterial content of dust particles during normal, semi-dust, and dust event days.

2 Materials and methods

2.1 Description of the study area

Ahvaz, the capital city of Khuzestan province, is one of the major cities of Iran, located in an arid area in southwestern of Iran in the vicinity of Iraq, Saudi Arabia, and Kuwait, which are the major sources of dust events in the Middle East. The geographical location of Ahvaz is $31^{\circ}20'N$, $48^{\circ}40'E$, and 18 meters above sea level. The presence of large industrial plants has turned Ahvaz into one of the most important industrial centers of Iran, attracting many immigrants to Ahvaz (Shahsavani et al. 2012b). Figure 1 presents the location of the sampling points and indicates Khuzestan province in the Middle East and in relation to the previously mentioned sources of dust events. As shown in the figure, Khuzestan province is adjacent to the Persian Gulf and Iraq from the south and west, respectively.

Fig. 1 Location of the study area and sampling station showing the nearby sources of dust storms



2.2 Sampling procedure

The concentrations of particulate matter (PM₁₀, PM_{2.5}, and PM₁) were measured using a Portable Aerosol

Spectrometer (Grimm Aerosol Technik GmbH, model 1.108, Germany). The Grimm device is an optical particle counter (OPC) and used for real-time measurement of PM in the range of 1.0–10.0 μm.

The air sampling for the presence of airborne bacteria was conducted using a microbial air sampler (Quick Take-30, SKC, USA), operating with a flow rate of 14.3 L/min; placed at 1.5–2 m above the ground level as a representative of human respiratory height. The sampling times were 15, 10, and 5 min during the normal, semi-dust, and dust event days, respectively. The samples were taken at all stations two times per day: regular morning (10:00–12:00) and afternoon (15:00–17:00) during the study period. Only for dust event days, sampling was performed in the early hours of the afternoon (13:00–14:00). Sampling was made every 6 days, but during dust events days, sampling was repeated in the same day. At each station, before sampling, the exterior part of the device was disinfected with a 70 % ethanol solution. Tryptic soy agar (TSA) was used as nutrient media for the bacterial growth. Cycloheximide was added to inhibit fungal growth. After collecting the air sample, the media were immediately sealed to prevent contamination and directly transported to the microbial analysis laboratory for culture. All the samples were incubated for 24–72 h at 37 °C (Kim et al. 2009; Zhu et al. 2003). After incubation, colonies on each plate were counted and the concentrations were calculated as colony forming units per cubic meter of air (CFU/m³). The species or genera of the cultured dishes were identified based upon their micro- and macro morphological characteristics, based on standard taxonomic keys (Rippon 1988).

2.3 Statistical analysis

The PM concentrations were analyzed using SPSS software version 17 (SPSS, Inc. Chicago, IL). All the graphs were plotted using Microsoft Excel 2007. Analysis of variance (ANOVA) with Tukey's post hoc test for pairwise comparisons was used to compare means in different stations, months, and sampling days. The one sample Kolmogorov–Smirnov test was employed to evaluate the normality of the data. Kruskal–Wallis test was used for the nonparametric equivalence of one-way analysis of variance if the normality assumption was rejected. The Mann–Whitney *U* test was employed for assessing significant difference of the bacterial concentrations during normal, semi-dust event, and dust event days. *P* values of <0.05 were considered significant. Pearson's rank correlation coefficient was used to determine the

relationship between the bacterial concentrations and some of meteorological parameters.

3 Results

3.1 Particulate matter concentrations

The concentrations of PM₁₀, PM_{2.5}, and PM₁ were measured on 26 days at three weather conditions (normal, semi-dust events, and dust event days) from November 2011 to May 2012. Table 1 presents the summary statistics for the concentrations of PM at different sampling stations during the study period. The overall mean concentrations of PM₁₀, PM_{2.5}, and PM₁ for the entire study period were 598.92 ± 775.32, 114.8 ± 129.45, and 34.5 ± 25.34 µg/m³, respectively. The corresponding maximum values for these PMs were 4,730.1, 774.4, and 164 µg/m³, respectively. The overall mean concentrations of PM₁₀ for the normal, semi-dust events, and dust events days were 144 ± 91.24, 416.4 ± 227.30, and 1,365.43 ± 873.49 µg/m³, respectively; the corresponding values for PM_{2.5} were 42 ± 21.65, 83 ± 55.96, and 238 ± 150.23 µg/m³, respectively.

3.2 Spatial–temporal trends in PM concentrations

The mean values of the PM₁₀, PM_{2.5}, and PM₁ concentrations over the sampling period are presented in Fig. 2. It is obvious from the figure that the highest mean and maximum values of the PM₁₀, PM_{2.5}, and PM₁ were observed in February and March 2011, while the lowest mean concentrations were measured in November and January. The highest mean PM concentrations were found at Naderi station, while the mean PM concentrations were lowest at Havashenasi station. The mean concentrations of the PM₁₀, PM_{2.5}, and PM₁ at Naderi station were 804.2, 141.5, and 37.2 µg/m³, respectively, while the corresponding values for Havashenasi station were 490.7, 95.6, and 33 µg/m³, respectively (see Table 1). The mean PM concentrations for different months over the study period are shown in Fig. 3.

3.3 Particulate matter ratios

Figure 4 shows the trends in the daily averages of PM_{2.5}/PM₁₀, PM₁/PM₁₀, and PM₁/PM_{2.5} ratios over

Table 1 Summary statistics of PM₁₀, PM_{2.5}, and PM₁ concentrations during the study period at different sampling stations for the three weather conditions

Stations	Weather conditions	PM ₁₀					PM _{2.5}					PM ₁					N
		Mean	Max	Min	SD	Med	Mean	Max	Min	SD	Med	Mean	Max	Min	SD	Med	
Havashenasi	^a Normal	127.6	436.3	29.6	83.3	104	42.7	100.4	11.4	24.85	37.6	28.57	76	4	19.03	24	39
	^b Dust event	1,199.84	2,691.4	141	637.09	1,260.75	197.55	452	19.4	107.34	203.02	41.48	85	7	20.34	40.66	20
	^c Semi-dust event	486.86	618.84	236.5	150.56	556.7	100.5	149	43.8	46.22	125	34.39	78	12	25.35	29.7	6
Naderi	Normal	230.37	426.75	83.4	113	254.7	51.75	82	14.6	21.05	51.26	24.21	58	5	13.46	20.6	11
	Dust event	1,491.5	4,260.3	551.5	986.6	1,277.09	250.2	701.2	100	161.88	224.8	55.38	152	23	34.36	49.6	12
Behdasht Ghadim	Semi-dust event	320.37	625.8	150.1	209.38	252.8	62.2	137.4	32.2	50.5	39.6	17.8	32	13	9.33	13.2	4
	Normal	143.23	496.76	37.2	97.12	114.13	41.47	88.2	10.9	20.35	41.9	23.83	53	4	12.3	21.27	26
Mohit Zist	Dust event	1,389.18	4,327.5	328.8	929	1,278.7	261.85	750.5	39.1	169.36	246	55.54	162	12	35.14	50.61	16
	Semi-dust event	397.05	705.7	182.3	227.39	350.1	75.42	158.1	30.4	60.03	56.6	21.18	40	10	13.37	17.6	4
Total	Normal	132.121	290.13	45.8	67.49	105.2	38.66	73.6	13.1	17.42	39	24.02	60	5	13.8	17.64	25
	Dust event	1,454.09	4,730.15	263.6	1,027.2	1,279.2	254.49	774.4	25.5	170.59	254.06	55.5	164	10	35.07	55.29	16
Total	Semi-dust event	443.7	909.7	144.6	357.38	360.25	88.55	197.8	23.6	80.59	66.4	24.8	54	10	20.43	17.65	4
	Total	598.92	4,730	29.6	775.32	240.95	114.8	774	10.9	129.45	55.34	34.49	164	4	25.34	28.29	183

^a Number of sample collected for normal days = 101

^b Number of sample collected for dust event days = 64

^c Number of sample collected for semi-dust event days = 18

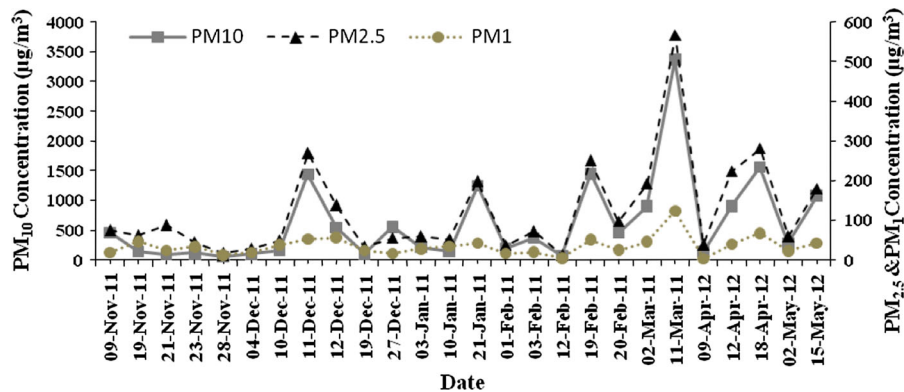
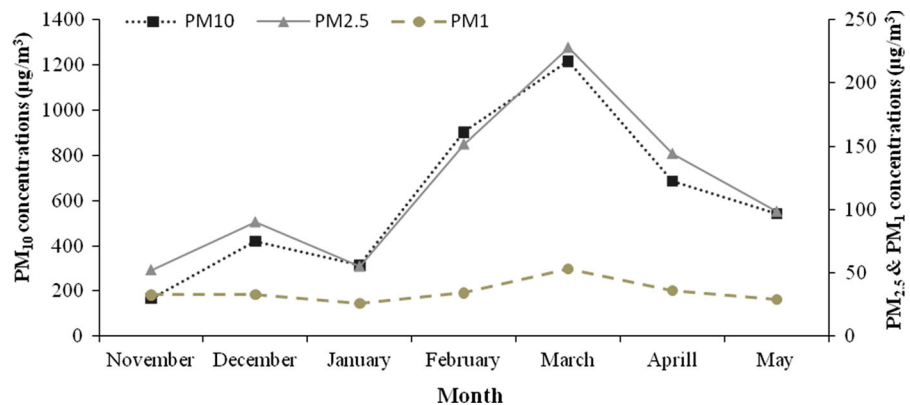


Fig. 2 Temporal trends in the daily average of PM_{10} , $PM_{2.5}$, and PM_1 concentrations during the study period in Ahvaz

Fig. 3 Temporal trends in the monthly average of PM_{10} , $PM_{2.5}$, and PM_1 concentrations over the study period in Ahvaz



the study period in Ahvaz. The ratios of $PM_{2.5}/PM_{10}$ ranged from 0.066 to 0.551. The corresponding values for PM_1/PM_{10} and $PM_1/PM_{2.5}$ ratios were 0.011–0.444 and 0.127–0.858, respectively. The mean $PM_{2.5}/PM_{10}$, PM_1/PM_{10} , and $PM_1/PM_{2.5}$ ratios for the entire study period were 0.257, 0.134, and 0.451, respectively. The statistical summaries of the PM ratios at different sampling stations are presented in Table 2. The trends in the PM ratios in different months are shown in Fig. 5. The PM ratios for the three weather conditions can be obtained from Table 2. For example, the mean $PM_{2.5}/PM_{10}$ ratios for normal, dust event, and semi-dust event days were 0.318, 0.178, and 0.189, respectively.

3.4 The temporal distributions of total culturable airborne bacteria

Figure 6 shows the temporal distributions of the total airborne bacteria over the study period. The concentrations of total bacteria in the ambient air of Ahvaz

city varied greatly in the different sampling days. The overall mean concentration of total bacteria during the study period was 620.6 CFU/m^3 . The highest concentration was observed in October ($2,097.9 \text{ CFU/m}^3$), while the lowest concentration was detected in April (18.6 CFU/m^3). There were significant differences in bacterial concentrations from November 2011 to May 2012 ($p < 0.05$).

3.5 Bacterial concentrations in different weather conditions and stations

The bacterial concentrations in different weather conditions and stations are shown in Fig. 7. The highest concentration ($2,097.9 \text{ CFU/m}^3$) was observed at Naderi station in dust event condition, while the lowest concentration (18.6 CFU/m^3) was observed at Havashenasi station in normal days. The mean concentrations for Mohit Zist, Naderi, Behdasht Ghadim, and Havashenasi stations were 665.2, 943.4, 657.6, and 437.8, respectively. The corresponding

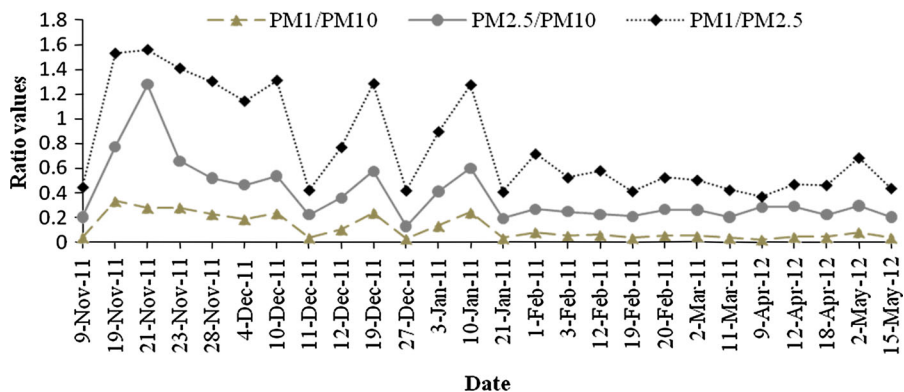


Fig. 4 Trends in daily average of $PM_{2.5}/PM_{10}$, PM_1/PM_{10} , and $PM_1/PM_{2.5}$ ratios over the study period in Ahvaz

Table 2 Summary statistics of $PM_{2.5}/PM_{10}$, PM_1/PM_{10} , and $PM_1/PM_{2.5}$ ratios over the study period at different sampling stations for the three weather conditions

Station	Weather condition	$PM_{2.5}/PM_{10}$				PM_1/PM_{10}				$PM_1/PM_{2.5}$			
		Mean	Max	Min	Med	Mean	Max	Min	Med	Mean	Max	Min	Med
Havashenasi	Normal	0.348	0.518	0.165	0.348	0.238	0.405	0.038	0.245	0.663	0.858	0.233	0.713
	Dust event	0.173	0.277	0.066	0.181	0.041	0.125	0.011	0.036	0.229	0.450	0.162	0.209
	Semi-dust event	0.205	0.270	0.106	0.225	0.072	0.167	0.031	0.053	0.332	0.620	0.236	0.274
Naderi	Normal	0.247	0.442	0.130	0.222	0.122	0.251	0.041	0.098	0.462	0.709	0.244	0.459
	Dust event	0.172	0.219	0.121	0.175	0.039	0.57	0.026	0.037	0.225	0.260	0.202	0.223
	Semi-dust event	0.187	0.222	0.131	0.198	0.061	0.089	0.050	0.052	0.330	0.404	0.231	0.343
Behdasht Ghadim	Normal	0.310	0.487	0.155	0.296	0.192	0.377	0.040	0.190	0.596	0.794	0.257	0.638
	Dust event	0.192	0.435	0.083	0.182	0.04	0.057	0.024	0.038	0.217	0.297	0.127	0.216
	Semi-dust event	0.175	0.224	0.112	0.181	0.052	0.056	0.046	0.054	0.314	0.407	0.250	0.300
Mohit Zist	Normal	0.311	0.551	0.172	0.304	0.200	0.444	0.073	0.167	0.616	0.819	0.359	0.648
	Dust event	0.173	0.212	0.089	0.174	0.039	0.051	0.026	0.039	0.232	0.400	0.196	0.223
	Semi-dust event	0.186	0.217	0.163	0.181	0.059	0.080	0.044	0.057	0.326	0.487	0.236	0.291
Total		0.257	0.551	0.066	0.223	0.134	0.444	0.011	0.089	0.451	0.858	0.127	0.404

Fig. 5 Trends in monthly average of $PM_{2.5}/PM_{10}$, PM_1/PM_{10} , and $PM_1/PM_{2.5}$ ratios over the study period in Ahvaz

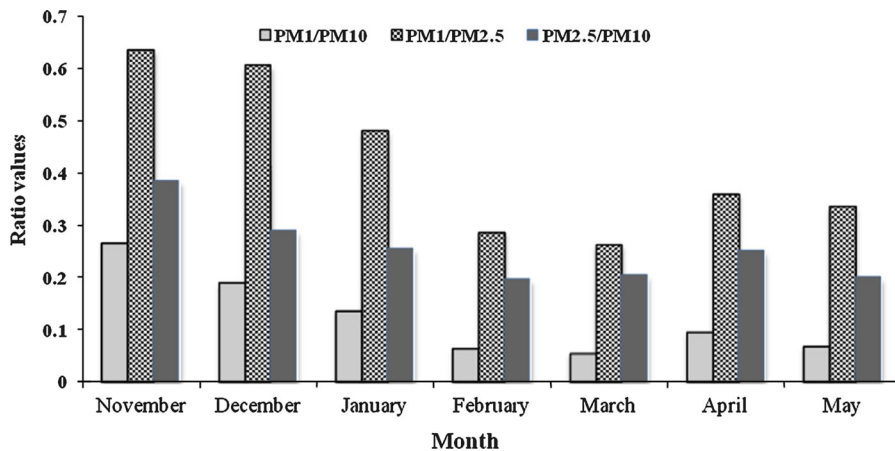


Fig. 6 Temporal trends in daily average of bacteria concentrations (CFU/m³) over the study period in Ahvaz

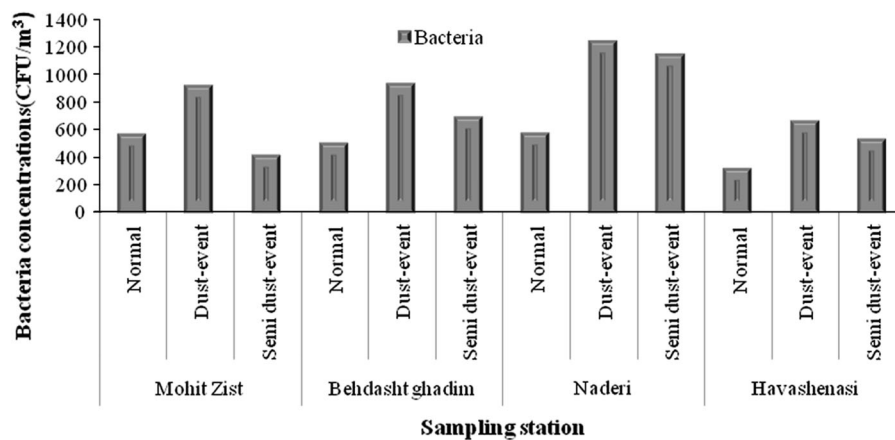
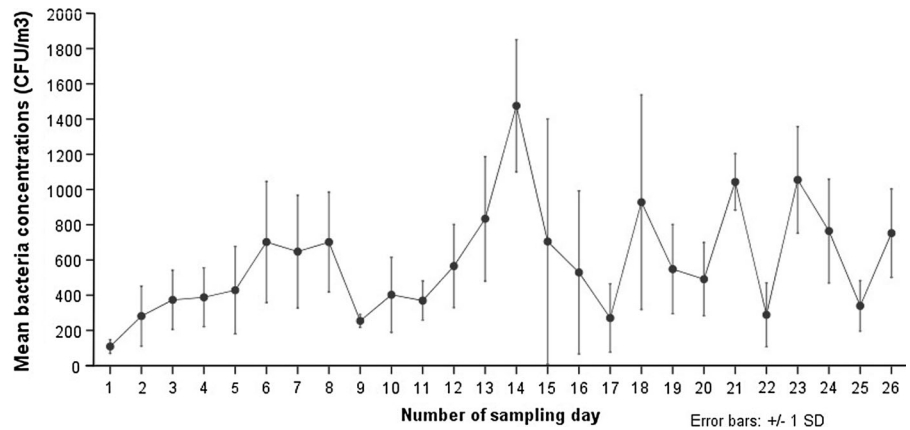


Fig. 7 Bacterial concentrations for the different weather conditions at different sampling stations

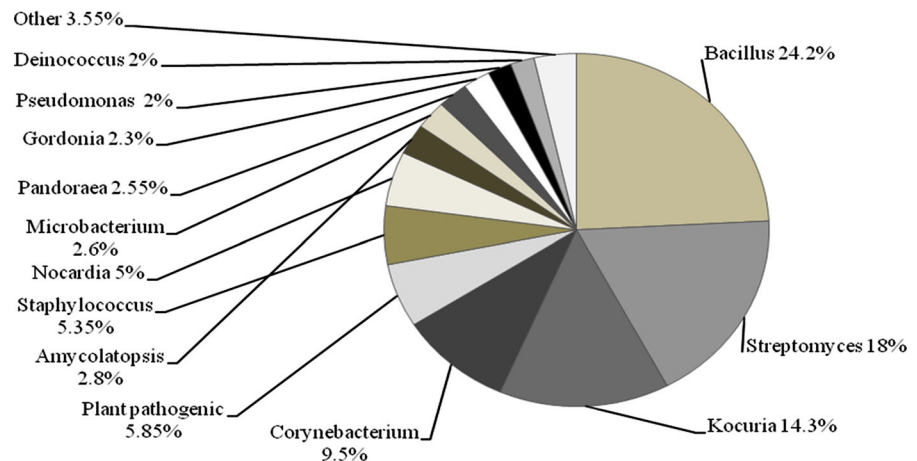
values for the normal, semi-dust event, and dust event conditions were 442.3, 889.9, and 663.8, respectively. There were significant differences between bacterial concentrations at different sampling stations ($p < 0.05$). No significant difference was found between Mohit Zist, Naderi, and Behdasht Ghadim ($p > 0.05$), but there was significant difference between Naderi (an area with high traffic and population density and more human activities) and Havashenasi (greener area) ($p < 0.05$). Significant difference in the bacterial concentrations was observed between the weather conditions ($p < 0.05$); this difference was more significant between normal and dust event days ($p < 0.01$).

3.6 Identification of isolated bacteria

The percentage of gram-positive bacteria was significantly higher than gram-negative ones during

the study period in the Ahvaz ambient air; the corresponding values were 89 and 11 %, respectively. Among the gram-positive bacteria, the percentage of *Rods* was higher than *Actinomycetes* and *Cocci*. Among *Rods* the maximum percentage belonged to *Bacillus* (24.2 %) and among *Actinomycetes* the maximum percentage belonged to *Streptomyces* (18 %), followed by *Kocuria* (14.3 %), *Corynebacterium* (9.5 %), *Nocardia* (5 %). According to the sampling days, the highest percentage for the gram-positive and gram-negative bacteria was found during dust events days. With regard to bacterial groups, 26 genera of culturable bacteria were identified from all the sampling stations during the study period. The most dominant genera in all the sampling stations were *streptomyces*, *Bacillus*, *kocuria*, *Corynebacterium*, and *Paenibacillus*. The most dominant bacteria and their percentage are shown in Fig. 8.

Fig. 8 Identified bacteria and their percentage in the ambient air of Ahvaz



3.7 Relationships between particulate matter and airborne bacteria concentrations

There was a significant correlation between the bacterial concentrations and particle matter during the study period ($p < 0.05$). Multiple stepwise linear regression procedure was used to estimate relationship between the bacterial concentrations and particle matter for normal, dust event, and semi-dust event days. The regression model showed that during normal days there were not significant relationships between PM_{10} , $PM_{2.5}$, and the bacterial concentration ($p > 0.05$); however, PM_1 had a positive association with bacterial concentration ($p < 0.05$). For dust event days, all fractions of PM had a significantly positive correlation with bacterial concentrations ($p < 0.05$). During semi-dust event days, a significant positive association existed between $PM_{2.5}$ and PM_{10} with bacterial concentrations ($p < 0.05$), but no significant correlation was found between PM_1 and bacterial concentrations ($p > 0.05$).

4 Discussion

Many researchers have investigated the airborne bacterial and fungal concentrations in different environments in the past several decades. The main aim of the present study was to investigate airborne bacteria concentrations in relation to PM in the ambient air of Ahvaz city during November 2011 to May 2012. The results showed that the PM concentrations had very large fluctuations in different months in Ahvaz. In recent years, the occurrence of dust storms was more

frequent in autumn and winter compared with the other seasons in Ahvaz city. In this study, the maximum concentrations of PM were found in March. The elevated PM concentrations in this month could be attributed to the dust storms occurrence. In a study conducted in Iraq, Kuwait, and Saudi Arabia, the regions that are believed to be the major sources of dust events in the Middle East, and located in vicinity of Ahvaz city, PM_{10} concentrations higher than $1,000 \mu\text{g}/\text{m}^3$ were observed (Draxler et al. 2001). Zhao et al. (2011) carried out a study in China and investigated the mass concentrations of PM_{10} and $PM_{2.5}$ before, during, and after the dust storm episode from March 20 to March 24, 2010. They reported that the mass concentrations of $PM_{2.5}$ and PM_{10} reached a striking high level during the dust storm episode (March 21–22, 2010) and peaked to 454.51 and $990.24 \mu\text{g}/\text{m}^3$ in the afternoon of March 21, 2010, respectively. The mean concentrations of $PM_{2.5}$ and PM_{10} during March 20–24, 2010 were 141.50 ± 108.82 and $322.03 \pm 237.38 \mu\text{g}/\text{m}^3$, respectively. However, the daily concentration of PM_{10} monitored by Xiamen EPA was $80 \mu\text{g}/\text{m}^3$ during the normal days. Vecchi et al. (2007) studied the PM_{10} concentrations in the urban area of Milan, Italy and reported that the maximum PM_{10} concentrations during the daytime and nighttime were 150 and $185 \mu\text{g}/\text{m}^3$, respectively. It is worth noting that studies on PM_1 are rare in spite of the fact PM_1 is very important for human health and having high penetration into the lungs (Tiwary and Colls 2010).

The highest mean concentration of PM was observed in Naderi station, which is located in

downtown and has high traffic and population density. The lowest mean concentrations of the PM_{10} , $PM_{2.5}$, and PM_1 were detected in Havashenasi station, which is located far from the city center, and it is a region without high traffic and population density, lack of industrial facilities, and with vegetation cover.

The PM ratios give an indicator to determine the relative importance of natural and anthropogenic sources to PM concentrations. A low $PM_{2.5}/PM_{10}$ ratio indicates that natural sources have a relatively higher contribution to the PM concentrations (Chaloulakou et al. 2005; Zakey et al. 2008). The average $PM_{2.5}/PM_{10}$ ratio observed in this study is much lower than those were found by the other studies. For instance, in the study conducted by Viana et al. (2003) in the Basque Country (Northern Spain), they reported that the $PM_{2.5}/PM_{10}$ ratios during the summer and winter were 0.8–0.9 and 0.6–0.7, respectively. The higher $PM_{2.5}/PM_{10}$ ratio in the summer in that study was attributed to the inland transport of industrial and anthropogenic pollutants, which were emitted along the valley of the river Nervion, and in a lower proportion from central and Eastern Europe. In addition, He et al. (2001) carried out a study in Beijing, China, and they reported a mean $PM_{2.5}/PM_{10}$ ratio of 0.64 for the entire study period. Gomišček et al. (2004) performed a study at an urban site in Austria and reported a $PM_{2.5}$ to PM_{10} ratio of 0.67, while on season basis, the mean $PM_{2.5}/PM_{10}$ ratios were 0.67 and 0.65 for the winter and summer, respectively. Therefore, these low ratios of our study can be considered to represent the importance of crustal materials and dust re-suspension as the factors influencing particulate levels at areas with temperate or dry climatic conditions like Ahvaz (Chaloulakou et al. 2005). The other reason might be due to the dust events, in which the main components, are expected to be coarse particles (Shahsavani et al. 2012b). The observed particle concentrations in the present study during the dust storm days were generally higher than those were observed during the Asian dust storms (Chen et al. 2004; Shen et al. 2009). It is noteworthy that also for non-dust days the PM_{10} concentrations had much higher values compared with the similar studies performed elsewhere worldwide (Shaka' and Saliba 2004; Viana et al. 2002, 2003).

There were great fluctuations in the bacterial concentrations during the study period, which could be attributed to different climate condition, sampling

conditions and times, and particle concentrations, etc. (Shaffer and Lighthart 1997).

It is believed that there is a positive correlation between bacterial concentration with type of region, human activities, automobile flow, and population density. Furthermore, vegetation and plants of the study area have significant impacts on the bacterial concentration in the atmosphere because they can disinfect bacteria by secreting volatile products (Fang et al. 2007). In the current study, the highest and lowest overall mean bacterial concentrations were observed at Naderi (as a site with more human activities, high traffic flow, and populated area) and Havashenasi (as a greener area with less human activities) stations, respectively. Statistically, there were significant differences in the bacterial concentrations at two stations. Our findings are consistent with other similar studies (Fang et al. 2007; Mouli et al. 2005; Shaffer and Lighthart 1997).

According to the previous studies, soil is the main source of airborne bacteria (Lighthart and Shaffer 1994). It was previously demonstrated that under adverse conditions such as desiccation, strong sunlight, and aerosolized chemical pollutants, gram-positive bacteria had greater resistance and survival ability than gram-negative bacteria (Fang et al. 2007). The severe shortage of vegetation and vicinity to desert area in Khuzestan province, Saudi Arabia, and Iraq cause warmth and dryness in Ahvaz, and it is ranked as the warmest place in Iran. Thus, the high percentage of gram-positive bacteria can be attributed to these aforementioned reasons. The results of this study are consistent with the results of other similar studies. For example, Fang et al. (2007) studied culturable airborne bacteria in the outdoor environments in Beijing, China; reported that the percentage of gram-positive bacteria was significantly higher than gram-negative bacteria; and accounted for about 80–86 % of total airborne bacteria content. In that study, the most dominant bacteria among all the bacterial genera were *Micrococcus*, *Staphylococcus*, *Bacillus*, *Corynebacterium*, and *Pseudomonas* (50 %). In addition, in the study conducted by Lou et al. (2012) in Hangzhou, the southeast of China, a total of 533 bacterial colonies were isolated and identified. The percentage of gram-positive bacteria accounted for about 84–90 % and, significantly, was higher than gram-negative bacteria in the air of the university campus. The dominant bacteria in that study

were similar to the study mentioned previously. Our findings are relatively consistent with these two studies. With respect to the previous case studies, it is difficult to determine whether the source of increased bacteria is a dust storm, local emissions, or some other sources. High correlations between culturable bacteria concentrations and all fractions of the PM during the dust event days in this study indicated that the desert dust might be the source of airborne bacteria in which a gram of desert soil may contain a large number (about 10^9) of bacterial cells (Burrows et al. 2009; Jeon et al. 2011).

The particle size associated with the observed airborne bacteria is significantly larger than the typical size of such bacteria, which is about 1 μm . It has been assumed that larger particles protect bacteria from environmental stresses. Perhaps, due to this reason, the bacteria attached to them are more likely to retain cultivability (Burrows et al. 2009; Lighthart 2000).

5 Conclusions

In the present study, the concentration of PM ($\text{PM} \leq 10 \mu\text{m}$), associated airborne bacteria, and the influence of meteorological factors on airborne bacteria have been evaluated at different locations of Ahvaz, the major city in southwestern of Iran. The concentrations of PM and related bacteria were investigated at different weather conditions, and the results showed that the weather conditions played an important role in the release and distribution of PM and micro-organism in the ambient air. For example, the PM concentration and, consequently, the airborne bacteria concentration were higher during dust event days. It also was found that the areas with high traffic and human activities had greater PM and airborne bacteria concentrations compared with the greener and low population density areas. There were significant differences in the bacterial concentrations at different sampling stations ($p < 0.05$), and significant difference in bacterial concentrations was observed between weather conditions ($p < 0.05$). The greater percentage of gram-positive bacteria (89 %) signifies that the bacteria might have been released from soil sources by natural events like dust storms. The most dominant genera in all the sampling stations were *streptomyces*, *Bacillus*, *kocuria*, *Corynebacterium*, and *Paenibacillus*. Statistically, PM had a positive and significant

correlation with the airborne bacteria concentrations ($p < 0.05$).

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