



Influence of meteorological parameters and PM_{2.5} on the level of culturable airborne bacteria and fungi in Abadan, Iran

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Abstract In recent years, monitoring of airborne bacteria and fungi concentrations has obtained increasing universal attraction not only for influences on ecological balance but also for evaluating their public health consequences. In this study, we aimed to investigate culturable airborne bacteria and fungi levels in different sites of Abadan, and their association with meteorological parameters and PM_{2.5} levels. Abadan is one of the most industrialized cities in the southwest of Iran where over the current decade

has experienced lots of dust storm episodes. In total, 400 air samples were collected in 6 months (autumn and winter) using a single-stage viable Andersen cascade impactor for sampling airborne bacteria and fungi and portable DustTrak Aerosol Monitor 8520 for measuring PM_{2.5} concentrations and meteorological parameters. Microbial concentrations showed a significant difference between various sites over the study period with averages of 569.57 ± 312.64 and 482.73 ± 242.86 CFU/M³ for bacteria and fungi, respectively. The air temperature had a significant effect on the concentration of both airborne bacteria and fungi. A significant positive correlation between relative humidity and fungi but no correlation between relative humidity and bacteria concentrations were observed. The average airborne PM_{2.5} concentrations of all sites among the study period was 93.24 ± 116.72 µg/m³. The atmospheric bacterial and fungal communities were strongly positively correlated with the ambient PM_{2.5} level. The levels of airborne bacteria and fungi along with PM_{2.5} in the air of the city were relatively higher than the recommended levels. Therefore, the best course of action is needed to control emission sources. Further studies are also needed to evaluate the clinical analysis of the health effects of exposure to these pollutants.

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1 Introduction

In recent years with the development of industrialization and increasing environmental problems such as dust storms that occurred frequently over southwestern Iran, air pollution has become more serious in this area and has raised government and public concerns (Soleimani et al., 2013). A huge mass of dust can move long distances and carry away many airborne pollutants (Kellogg & Griffin, 2006). Among them, suspended particulate matter plays an important role in the air pollution of this area and has adverse effects on human health (Niu et al., 2010; Shamsavani et al., 2012). Fine particulate matters (PM_{2.5}; particulate matters with an aerodynamic diameter \leq of 2.5 μ m), due to their fine size and leaning to stay for a long time in the air, have a big chance to penetrate deep into the lungs and enter into the bloodstream and tissues, causing respiratory and vascular diseases (Franzetti et al., 2011; Liu et al., 2018). Along with physical and chemical components, biological elements also exist in particulate matter that are defined as bioaerosols (). Against the vast amount of information about chemical components of atmospheric particulate matter, few studies focused on the biological composition of ambient air. Over the past decades, an increase in awareness about their hazards has promoted an increasing interest in knowing more about the bioaerosols (Genitsaris et al., 2017; Xu et al., 2017).

Bioaerosols are omnipresent all over the world, either as an individual organism or attached to the surface of other non-biological particles (Innocente et al., 2017; Zhen et al., 2017). These atmospheric aerosols largely drive from natural sources, such as soils, water, plants, leaf surface, and animal and human faeces. The main composition of them are bacteria, fungi, viruses and pollen (Bragoszewska & Pastuszka, 2018; Du et al., 2018a, 2018b, 2018c) that ranges from 0.1 to 100 μ m in diameter and thousands to millions of cells per cubic meter of air (Bragoszewska & Pastuszka, 2018; Innocente et al., 2017; Xu et al., 2017; Zhen et al., 2017). Some investigations reported that bioaerosols comprise up to 25 weight per cent of the total atmospheric aerosols, and another study reported that 5–10% of the total suspended particulate mass is bioaerosols (Cao et al., 2014; Du et al., 2018a, 2018b, 2018c; Franzetti et al., 2011; Li et al., 2017).

Studies have shown that bioaerosols are prominent in the surrounding environment, can influence ecological balance, atmospheric processes, and contribute to the formation of clouds and condensation nuclei (Du et al., 2018a, 2018b, 2018c; Hurtado et al., 2014). On the other hand, bioaerosols can put human health in danger through the release of some pathogenic bacteria and fungi from different sources. Exposure to the bioaerosols, depending on their biological and physical properties, chemical composition and size distribution, deposition site and inhaled quantity in the respiratory tract, can lead to some health effects such as eye, skin and urinary tract infection, respiratory diseases, and increased allergen burden leading to an increased incidence of asthma and rust disease in plants (Maki et al., 2013; Maron et al., 2005). Bioaerosols not only affect the community living nearby their sources of emission but also can move farther through air transport and influence other populations (Brodie et al., 2007; Degobbi et al., 2011; Gao et al., 2016). However, considering their potential risks, there is no formally regulated standard for bioaerosols levels in the ambient air by now. Most of the investigations have focused on specific sources such as occupational environment, wastewater treatment plants, and dust events, but less is known about the ambient natural microbial community in urban areas (Chen et al., 2012; Du et al., 2018a, 2018b, 2018c; Raisi et al., 2010).

In the present study, we focused on culturable bacteria and fungi because of their high interactions with other air pollutants and sensitivity to meteorological parameters, such as air temperature, etc. So, we attempted to investigate the concentration of atmospheric culturable bacteria and fungi in relation to ambient PM_{2.5}, location, dates and meteorological factors in different sites of Abadan city over 6 months (autumn and winter). To the best of our knowledge, so far, there is no study on outdoor bioaerosols concentration and the effect of meteorological factors and ambient PM_{2.5} on their concentration conducted in this area of Iran. This study can provide references for a better understanding of outdoor air quality in industrialized and dusty areas which is useful in emission control planning and health risk assessment studies.

2 Material and methods

2.1 Study area and sampling sites

The study was carried out in Abadan, a city of Khuzestan province, southwest of Iran located at 30,339,167° north and 48,304,167° east, with a population of approximately 231,500 people. Abadan has a desert climate with mild, dry winter (16–20 °C) and warm, wet summer (around 45 °C) and experiences a few sand and dust storms per year. The prevailing wind direction is most often from the north (25.4%) and northwest (40.2%) with average wind speeds of 10.1 mph, which is maximum in June and minimum in October. The whole area is flat but some elevated features are created artificially in some area. Two rivers named Arvandrud and Bahmanshir estuaries of Karun river flow through the city and down to 50 km join to the Persian Gulf. The vegetation area is mostly located around the coastal plain of these rivers. Abadan is an industrial city having a large oil refinery site and petrochemical complex located at the heart of the city. Ambient air samples were collected from 10 representative sites selected according to different characteristics that are shown in Table 1, and such a way to cover all areas of the city (Fig. 1). Sampling was conducted for 20 non-consecutive days, each day from 10 cities, from October 2017 to March 2018 (6 months).

2.2 Air sampling methods for bioaerosols

The samples were collected with a single-stage viable Andersen cascade impactor (MAS 100 Merck) linked

to a vacuum pump (SKC MCS Flite; 0–20 l/min) with an average flow rate of 12 l/min, calibrated by a rotameter, for 2–3 min sampling time. The ambient air sampling set was located on a stand 1.5 m above ground level as a representative of human respiratory height and at a distance of at least 2 m away from nearby physical barriers (Fang et al., 2005; Wu et al., 2000). The sampler with tube linings was disinfected with ethanol 70% and air-dried before each sample collection. In total 400 air samples (200 samples for bacteria and 200 samples for fungi) were collected among the 6 months. For stability, all samples were collected during the day at times between 9:00 to 15:00. The culture plates were transported to the site and then to the laboratory by a cold box.

2.3 Quantification of culturable bacteria and fungi

The air samples were directed into agar Petri dishes located in the impactor, one containing Tryptone Soya Agar (TSA) media for the culturing of bacteria and other containing Sabouraud Dextrose Agar (SDA) media for fungal culture. Cycloheximide (500 mg/L) was used to inhibit fungal growth in the bacteria culture media while chloramphenicol (100 mg/L) was used to suppress bacteria growth in the fungal culture media. After wrapping samples with sterilized aluminium foil, the specimens were brought back to the laboratory in a cold box and incubated at 35 ± 0.5 °C for 28–48 h for the bacteria samples, and at 25 ± 0.5 °C for 72 h for the fungal samples (Fang et al., 2005; Haas et al., 2014). The total numbers of bacteria and fungi in the ambient air were determined as colony-forming units per cubic meter of air (CFU/

Table 1 Characteristics of selected sites for air sampling in the city of Abadan

Site no	Name	Main features	Geographic coordinates
1	Shahid Jami St	River area	30°22'16.62"N, 48°16'49.66"E
2	7 th Tir Blvd	highway	30°22'39.68"N, 48°15'17.73"E
3	Valiasr Blvd	School District	30°22'49.41"N, 48°14'15.67"E
4	Baharestan Blvd	River area/ Wastewater disposal	30°21'40.42"N, 48°14'37.21"E
5	Besides the oil refinery	Industrial zone	30°20'32.56"N, 48°16'0.49"E
6	Amiri Blvd	Densely Populated/city center	30°20'0.03"N, 48°17'10.73"E
7	Velayat Blvd	Gastronomic District	30°20'0.17"N, 48°18'2.38"E
8	Tayyeb Blvd	Recreational green area	30°20'57.45"N, 48°18'0.41"E
9	Shohada Blvd	Residential area	30°19'47.01"N, 48°19'8.18"E
10	Ghaem Town	Solid waste disposal	30°19'1.24"N, 48°19'55.10"E

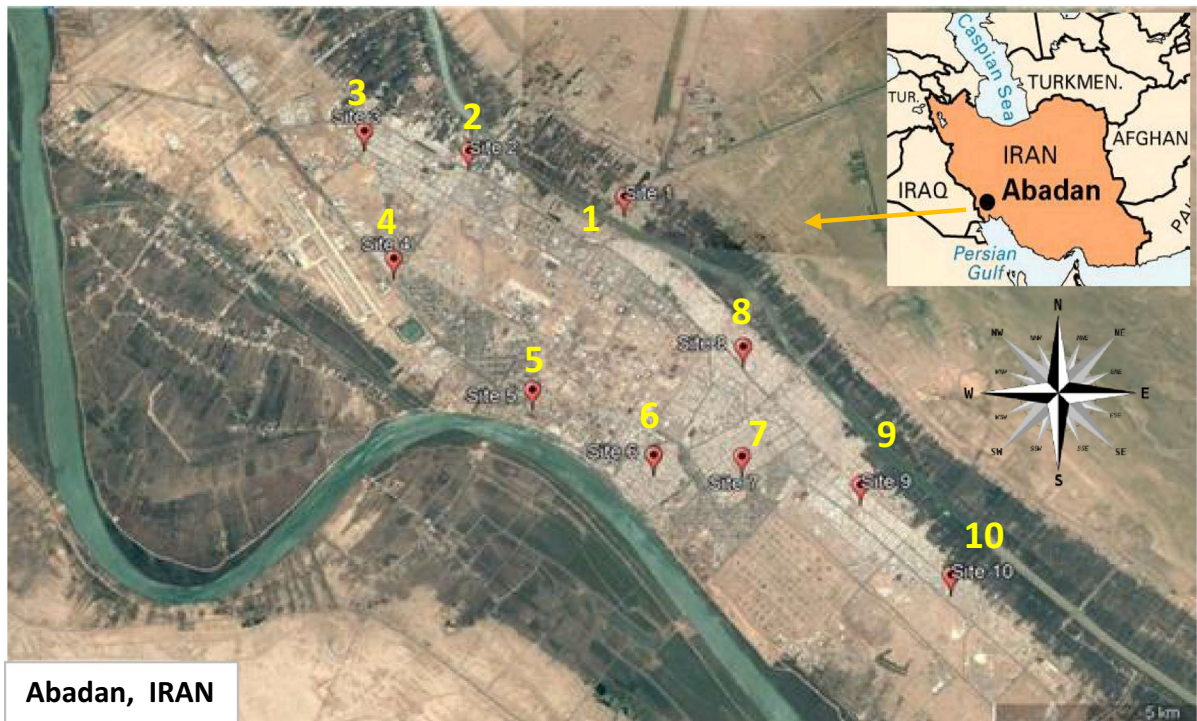


Fig. 1 The location of sampling sites in the city of Abadan, Iran

m^3) using the positive-hole correction method based on the following formula:

$$\text{CFU}/\text{m}^3 = \frac{T \times 1000}{t(\text{min}) \times F(\text{l}/\text{min})}$$

where T is the number of bacteria or fungi colonies, t (min) is the duration of sampling, F (l/min) is the pump flowrate and 1000 is the conversion factor of litre to the cubic meter.

2.4 Measurement of $\text{PM}_{2.5}$ and meteorological parameters

In addition to bacteria and fungi sampling of ambient air in each selected site, we measured airborne $\text{PM}_{2.5}$ concentrations in the same point by a portable Dust-Trak Aerosol Monitor (Model TSI-8520, Italy). Relative humidity and temperature also were measured at the same time by TSI-8520 digital during the sampling period (Fang et al., 2008). The other meteorological parameters such as wind velocity and wind direction

data were obtained from the Isfahan Weather Forecast Organization and included in the study.

2.5 Statistical analysis

One-way analysis of variance (ANOVA) was carried out to compare means in different sites. To find out the normality of the data, the one-sample Kolmogorov–Smirnov test was used. Nonparametric Spearman's rank correlation analysis was employed to evaluate the relationship between the concentration of airborne bacteria and fungi and meteorological parameters, as well as $\text{PM}_{2.5}$. A p -value of <0.05 was considered as a significant difference for a confidence level of 95%. IBM SPSS ver. 24.0 was used for all the data analysis.

3 Results

3.1 Spatial variation of airborne bacteria and fungi concentrations in the city

The mean concentration of bacteria and fungi at different sampling sites during the study period are presented as CFU/m³ in Table 2. There were extreme differences in the concentration of the bioaerosols in

the air of all sites, while the highest level of airborne bacteria and fungi were detected at sites 1, amounting to 878.81 ± 676.81 and 706.05 ± 479.94 CFU/m³, respectively. The lowest concentration of bacteria and fungi were measured at site 8, accounting for 312.12 ± 208.12 and 272.72 ± 162.14 CFU/m³, respectively. Figure 2 illustrates the concentration of airborne bacteria and fungi in representative sites during the sampling period. The microbial content of

Table 2 The concentration ranges of airborne bacteria and fungi (CFU/m³) in the sites during the sampling period

Site no	Sample size	Bacteria			Fungi		
		Min	Max	Mean ± SD (CFU/m ³)	Min	Max	Mean ± SD (CFU/m ³)
1	20	242.42	2484.42	878.81 ± 676.81	272.72	1818.18	706.05 ± 479.94
2	20	151.51	1848.50	633.32 ± 392.39	90.90	848.48	433.33 ± 238.21
3	20	0.00	1363.63	356.06 ± 293.44	30.30	1000.00	362.11 ± 239.71
4	20	60.60	1848.48	671.20 ± 489.24	242.42	1363.63	615.14 ± 346.63
5	20	60.60	1818.18	471.20 ± 397.11	90.90	939.40	507.57 ± 294.59
6	20	90.90	2121.21	751.51 ± 531.68	121.21	1394.00	593.94 ± 354.27
7	20	0.00	878.78	399.99 ± 246.10	60.60	848.48	421.20 ± 266.88
8	20	30.30	787.87	312.12 ± 208.12	30.30	545.45	272.72 ± 162.14
9	20	30.30	1030.30	412.11 ± 246.65	30.30	848.48	328.78 ± 211.84
10	20	60.60	2727.27	812.12 ± 694.90	121.21	2151.51	599.09 ± 445.41

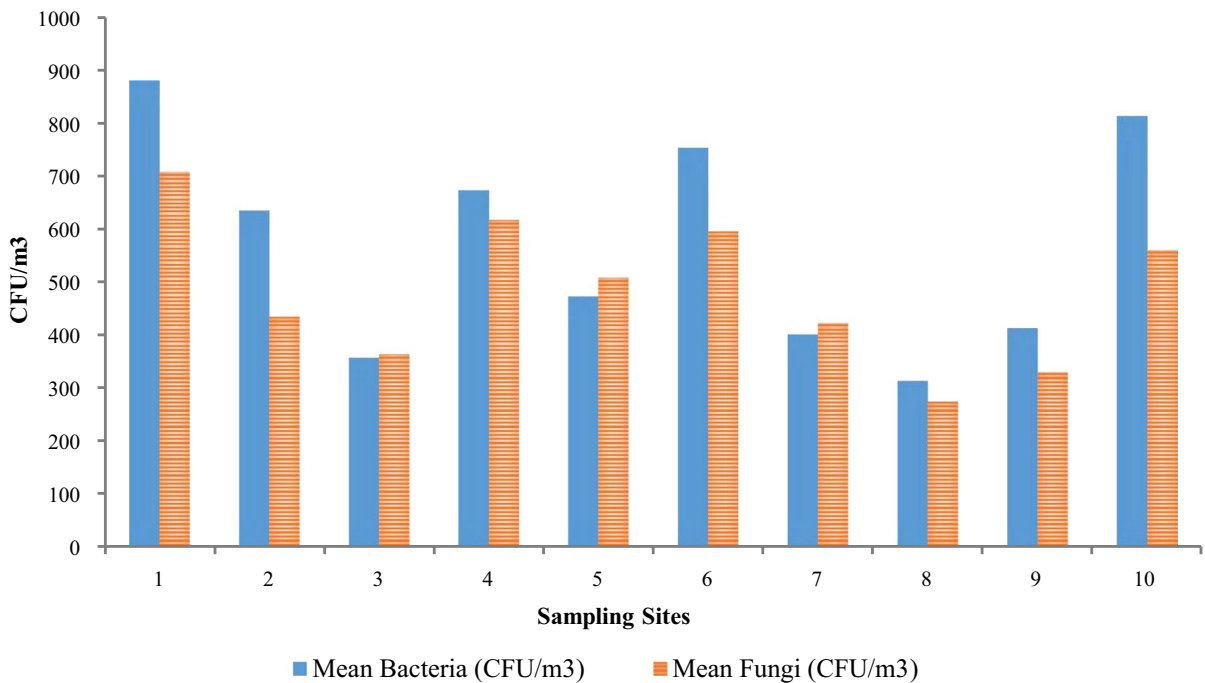


Fig. 2 Spatial variation of mean airborne bacteria and fungi in the study area

ambient air displayed a significant difference between different sites of Abadan ($p < 0.05$).

3.2 Temporal variation of airborne bacteria and fungi concentrations during the study period

The variation of airborne bacteria and fungi during the sampling period are shown in Table 3. The mean concentration of airborne bacteria and fungi for the entire study period were 569.57 ± 312.64 and 482.73 ± 242.86 CFU/m³, respectively. The corresponding higher mean value for bacteria was in December with 1287.87 CFU/m³ and that for fungi, was in January with 909.09 CFU/m³, whereas the lowest concentration of bacteria and fungi was in November with 127.27 and 136.36 CFU/m³, respectively. The mean concentration of airborne bacteria was higher than fungi. In addition, there was a significant correlation between the concentration of airborne bacteria and fungi ($p < 0.01$). Also, as can be seen in Figs. 3 and 4 the frequency and the dispersion of total bacteria and fungi during the sampling period did not show a regular trend. However, a higher

concentration of both bacteria and fungi was detected in December and January.

3.3 Association of airborne bacteria and fungi levels with PM_{2.5} and meteorological factors

Table 4 illustrates the averages of PM_{2.5} concentrations in the sampling sites during the study period. The mean concentration of PM_{2.5} in the ambient air over the study period was 93.24 ± 14.05 µg/m³ with the maximum level of 504.95 µg/m³ in January and the minimum level of 10.94 µg/m³ in November. As demonstrated in Table 5, there was a strong correlation between the concentration of bacteria and fungi, and PM_{2.5} ($p < 0.05$). Among all the measured factors, PM_{2.5} was the most correlated factor with the concentration of airborne bacteria and fungi. Figures 5 and 6 also present the association between airborne bacteria and fungi with PM_{2.5} concentrations, respectively.

The meteorological variables in the dates of sampling are shown in Table 4. The air temperature was in a range of 38.6–16.0 °C (average: 23.28 °C), with the highest in October and the lowest in

Table 3 The concentration ranges of airborne bacteria and fungi (CFU/m³) in different days of the sampling period

Date	Sample size	Bacteria			Fungi		
		Min	Max	Mean ± SD	Min	Max	Mean ± SD
17/10/04	10	30.30	484.84	269.70 ± 143.17	30.30	333.33	160.60 ± 95.88
17/10/18	10	60.60	666.66	363.63 ± 185.15	60.60	333.33	215.15 ± 98.40
17/11/01	10	181.81	1181.81	642.42 ± 387.50	303.03	848.48	630.30 ± 193.14
17/11/04	10	212.12	1242.42	536.36 ± 338.14	363.63	909.00	666.66 ± 149.81
17/11/15	10	212.12	636.36	412.12 ± 149.96	181.81	787.87	375.75 ± 216.26
17/11/22	10	30.30	242.42	127.27 ± 85.47	30.30	272.72	136.36 ± 79.85
17/11/29	10	90.90	2303.03	636.36 ± 259.10	242.42	1272.72	654.54 ± 378.53
17/12/10	10	484.84	2484.84	375.75 ± 159.84	454.54	1606.06	809.09 ± 329.50
17/12/13	10	181.81	1000.00	654.54 ± 302.42	272.72	1363.63	715.15 ± 352.01
17/12/27	10	181.81	727.27	1281.81 ± 772.85	181.81	575.75	427.27 ± 125.71
18/01/10	10	333.33	1272.72	581.81 ± 449.42	303.03	1212.12	624.24 ± 327.05
18/01/20	10	545.45	2727.27	600.00 ± 247.34	515.15	1818.18	909.09 ± 376.05
18/01/24	10	0	1545.45	336.36 ± 182.07	272.72	2151.51	854.54 ± 595.33
18/01/28	10	242.42	93.40	934.00 ± 611.28	121.21	575.75	415.15 ± 163.53
18/02/07	10	60.60	575.75	287.87 ± 200.63	60.60	545.45	318.18 ± 164.90
18/02/13	10	272.72	2394.00	727.27 ± 603.36	272.72	848.48	606.06 ± 192.07
18/02/20	10	0	636.36	248.48 ± 156.36	90.90	787.87	394.00 ± 212.36
18/02/21	10	272.72	2121.21	727.27 ± 603.36	30.30	363.63	266.66 ± 95.61
18/03/07	10	90.90	484.84	248.48 ± 156.36	60.60	393.93	194.00 ± 108.04
18/03/17	10	181.81	848.48	424.24 ± 209.95	121.21	545.45	281.81 ± 143.60

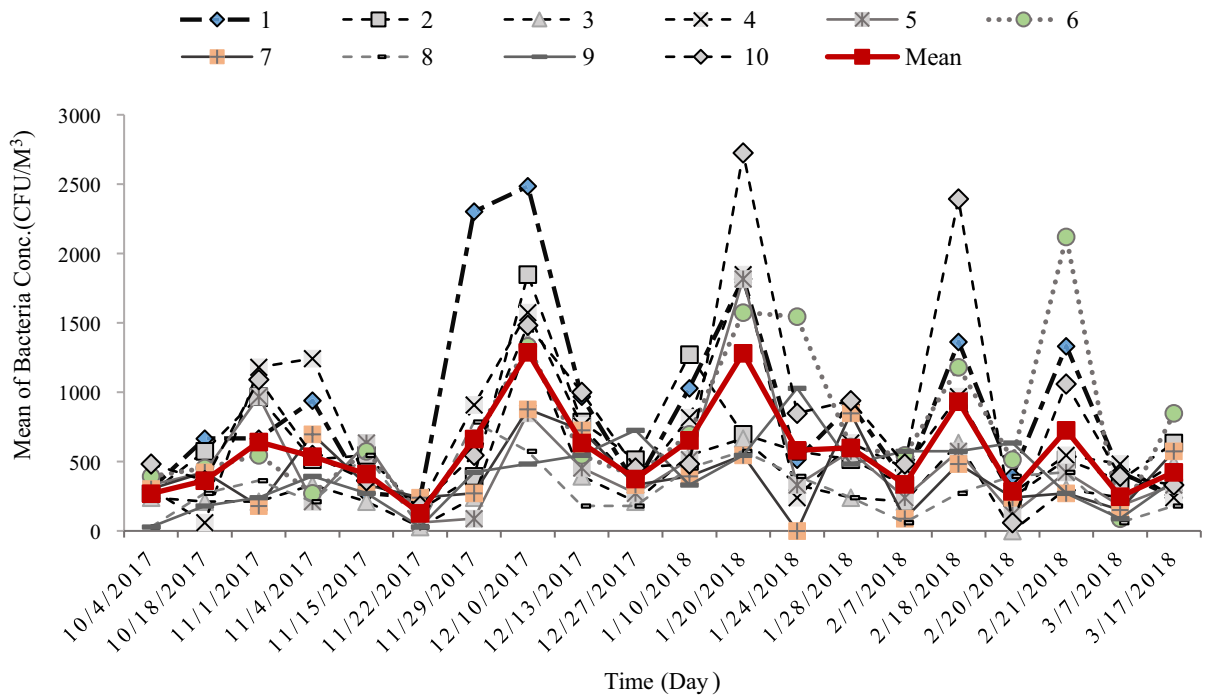


Fig. 3 Temporal variation of mean airborne bacteria concentrations in 10 sites during the sampling period

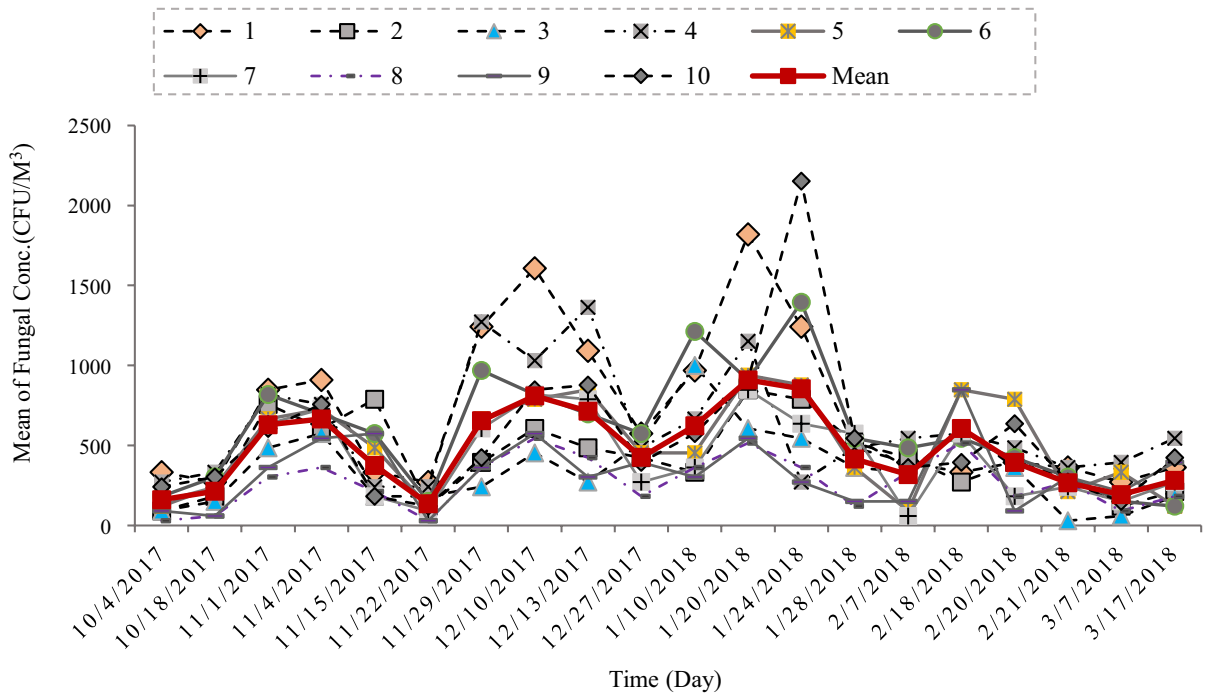


Fig. 4 Temporal variation of mean airborne fungal concentrations in 10 sites during the sampling period

Table 4 Mean meteorological parameters and airborne PM_{2.5} concentrations during the sampling period

Date	Temperature (C°)	Relative humidity (%)	Mean Wind velocity (m/s)	Max Wind velocity (m/s)	Wind Direction	PM _{2.5} * (µg/m ³)
17/10/04	38.7	39	2.0	4	E	23.94
17/10/18	33.7	24	2.0	5	N	29.31
17/11/01	29.3	43	2.0	6	N	141.3
17/11/04	30.0	52	4.0	6	SE	117.02
17/11/15	24.7	52	0.0	3	W	40.55
17/11/22	25.0	54	0.0	3	NW	10.87
17/11/29	20.7	72	2.0	5	NW	30.21
17/12/10	16.3	54	3.0	7	W	252.3
17/12/13	16.3	58	2.0	2	NW	41.93
17/12/27	21.7	56	2.0	5	NW	37.87
18/01/10	16.0	48	2.0	3	N	33.58
18/01/20	16.3	50	4.0	6	NW	504.95
18/01/24	21.7	48	0.0	4	SE	96.4
18/01/28	16.3	52	4.0	6	NW	12.74
18/02/07	24.0	18	0.0	3	NW	28.85
18/02/13	19.0	31	5.0	8	SE	203.54
18/02/20	18.7	42	0.0	15	NW	97.22
18/02/21	22.0	29	2.0	3	NE	59.41
18/03/07	30.0	26	2.0	3	SE	17.22
18/03/17	25.3	48	6.0	9	NW	77.98
Average	23.28	45.00	2.2	5.3	–	92.86

*The updated WHO guidelines for PM_{2.5}: Annual average concentration ≤ 5 µg/m³; 24 h average concentration ≤ 15 µg/m³ (not more than 3–4 days per year)

Table 5 Spearman correlation coefficients between the concentration of airborne bacteria and fungi and meteorological parameters, and PM_{2.5}

	Temperature (C°)	Relative humidity (%)	Wind velocity (m/s)	PM _{2.5} (µg/m ³)
Bacteria	$p < 0.05$ (−0.618 ^{**})	$p > 0.05$	$p > 0.05$	$p < 0.05$ (0.652 ^{**})
Fungi	$p < 0.05$ (−0.607 ^{**})	$p < 0.05$ (0.501 [*])	$p > 0.05$	$p < 0.05$ (0.688 ^{**})

^{**}Correlation is significant at the 0.01 level (2-tailed).

^{*}Correlation is significant at the 0.05 level (2-tailed)

December. The average relative humidity was 45%, the highest was 72% occurring in November and the lowest was 22% cast in February. Furthermore, the average wind velocity was 3.7 m/s within a range of 0–15 m/s with a maximum average of 5.3 ± 0.64 m/s. The Spearman correlation coefficients between the concentration of airborne bacteria and fungi versus temperature, relative humidity, and wind velocity are shown in Table 5. There was a significant negative correlation between

temperature and bacteria, and temperature and fungi concentrations ($p < 0.05$). Whereas, significant positive correlation between relative humidity and fungi concentration was found ($p < 0.05$), while there was no correlation between relative humidity and bacteria concentration ($p > 0.05$). In addition, the wind speed showed no statistically significant correlation with both bacteria and fungi concentration ($p > 0.05$).

Fig. 5 Association between the mean concentrations of bacteria and PM_{2.5}, and the meteorological parameters

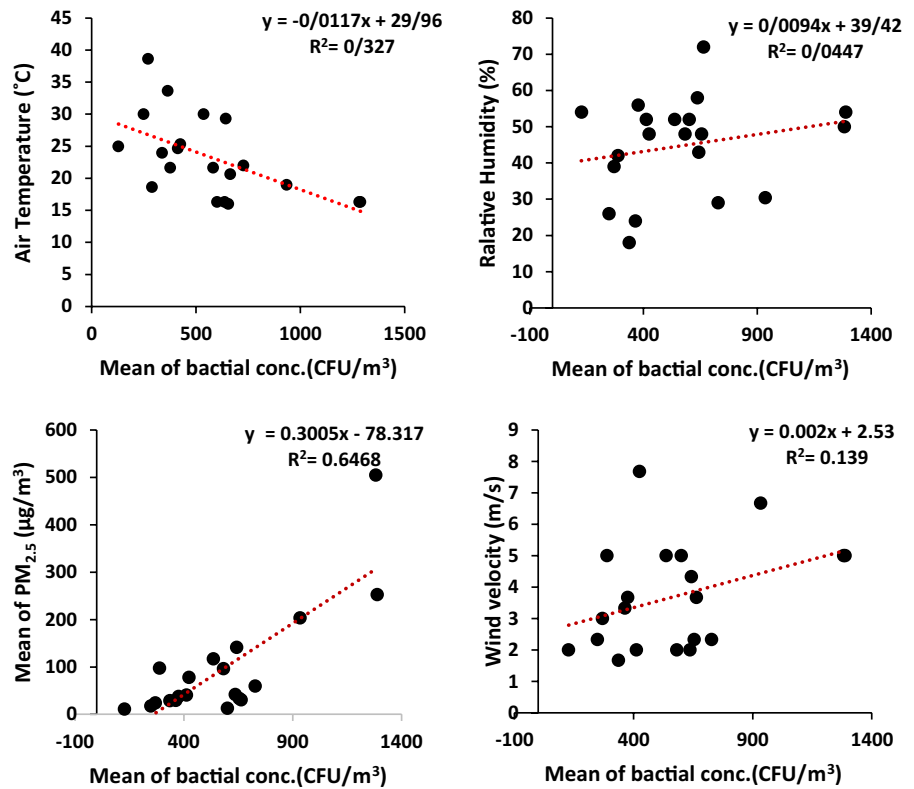
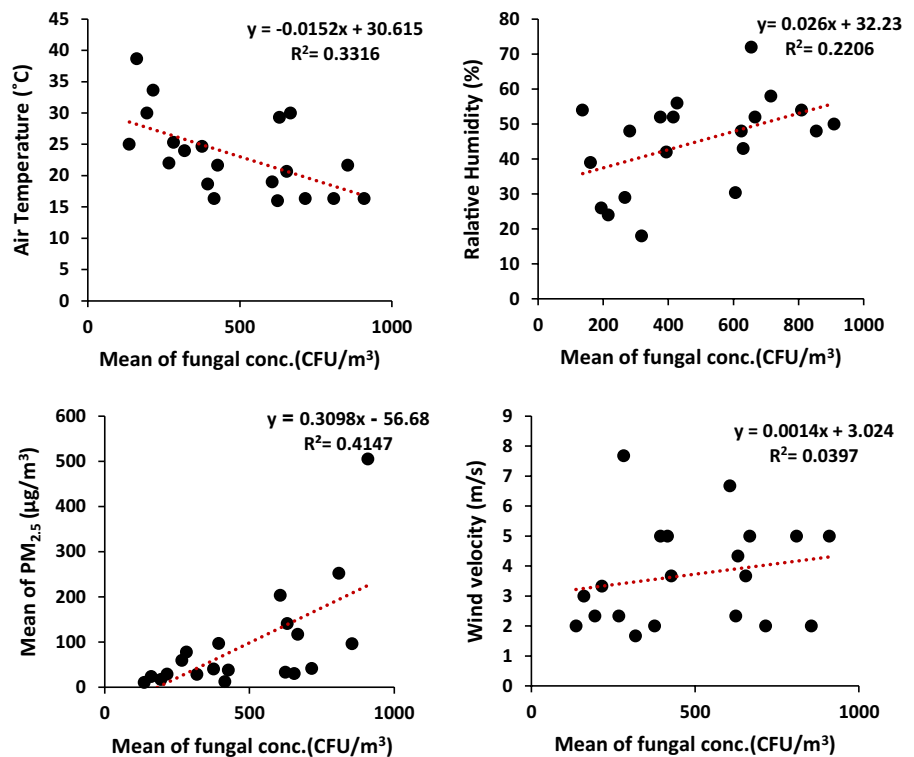


Fig. 6 Association between the mean concentrations of fungi and PM_{2.5}, and the meteorological parameters



4 Discussion

Bacteria and fungi concentrations were alterable by sites. In site 1 the concentrations were approximately triple times higher than those in site 8. Moreover, higher bacteria and fungi concentrations were detected in sites 10 and 4, respectively. Fang et al. found a positive correlation between ambient bioaerosols and human activities, population density and region type (Fang et al., 2005). A possible reason for the high bioaerosol levels of these sites may be their release from domestic and industrial wastewaters produced in the city and discharged to the rivers near these sites. Whereas, lower microbial concentration was detected in the air near the green lands where has relatively clean air. In addition, the plants can decrease the concentration of bioaerosols by their volatile products (Fang et al., 2008). High airborne bacterial and fungal concentrations were also observed in sites 5 and 6, the downtown, populated and industrial zones. In a study in Mexico, airborne microbial levels varied from an average of 230 ± 130 CFU/m³ in the coastal reference site to an average of $40,100 \pm 21,689$ CFU/m³ in the Tijuana River valley. The highest concentration has been reported near the populated river area with relatively intense human and animal activities (Hurtado et al., 2014). In contrast, we found a significant concentration of bacteria and fungi around the industrial regions. The concentrations we reported here for the sites located near the suburban and low polluted areas followed the study results in Guangzhou, China (Chen et al., 2012). However, Rodríguez et al. evaluated the temporal variability of PM_{2.5} and its associated microorganisms in the central Iberian Peninsula and found no temporal differences in microbial counts (Rodríguez et al., 2020).

Several studies have been conducted to quantify the level of airborne bacteria and fungi in different areas, however, we could not find any recommendation or standard for their level in the ambient air. Our study intended to supply initial data in this field and to compare them with similar studies conducted worldwide. The mean values of airborne bacteria and fungi detected in this study were nearly similar to the reports of Li et al. (bacteria: 565 ± 464 and fungi: 399 ± 371 CFU/m³) (Li et al., 2017), Du et al. (bacterial: 20–383 and fungal: 60–930 CFU/m³) (Du et al. 2018a; 2018b; 2018c), Wang et al. (bacteria:

440 ± 77 CFU/m³) (Wang et al., 2012) and Bragoszewska and Pastuszka (bacterial: 50–300 CFU/m³) (Bragoszewska & Pastuszka, 2018). However, we detected different ranges compared to the reports of Gao et al. (mean viable bacteria: 1110 ± 976 and fungi: 948 ± 978 CFU/m³) (Gao et al., 2016) and O’Gorman et al. (mean viable fungi: 915 CFU/m³) (O’Gorman & Fuller, 2008). There were no obvious reasons for these differences, but they may correspond with different experimental and sampling approaches, different types of culture media (bacterial and fungal growth substrate), geographic location, and mainly various meteorological and environmental conditions in these regions (Shaffer & Lighthart, 1997).

Given the geographic and meteorological conditions, Khuzestan, especially Abadan city experiences a long period of hot climate (March–October). The average temperature in this period of study was 23.27 ± 1.43 °C. Previous studies have shown that temperature over 24 °C decreases growth and survival of gram-positive and gram-negative bacteria, such as *Pseudomonas*, *Salmonella* and *Escherichia* (Handley & Webster, 1993). Thus, dry weather and strong solar radiation on high-temperature days can increase the die-off rate of airborne bacteria and fungi, and significantly affect their culturability (Li et al., 2017). Xu AL et al. reported that unfavourable conditions for microorganisms in winter decrease their concentration in the atmosphere (Xu et al., 2017). Furthermore, a study in Silesia, Poland reported that the seasonally average concentration of culturable bacteria was maximum in the spring and minimum in the winter (Bragoszewska & Pastuszka, 2018).

The influence of relative humidity on bacteria and fungi concentrations is complicated. In this study, we could not find a significant correlation between bacteria concentration and relative humidity, while fungi showed a positive correlation. Desired temperature and relative humidity for the growth of fungi has been reported to be 19.4 ± 5.1 °C and $70.7 \pm 12.5\%$ (Li et al., 2017) Li et al. also reported a high concentration of airborne fungi in the autumn which is following our study; whereas, the death ratios of bacteria was increased with increasing relative humidity (Li et al., 2017). Another study in Sao Paulo reported a negative correlation between the ambient level of colourless ascospore fungi and humidity and suggested that low humidity associated with heavy traffic could

suspend the road dust and be the reason for high aerosolization of the crustal elements, therefore increasing the release of bioaerosols from vegetation and soil (Degobbi et al., 2011).

In the present study, the concentration of ambient $PM_{2.5}$ ranged from 10.94 to 504.95 $\mu\text{g}/\text{m}^3$, and with increasing $PM_{2.5}$ level the concentration of ambient bacteria and fungi were increased. The results showed that the bacteria and fungi are a significant portion of the $PM_{2.5}$ ($p < 0.05$). As presented in Table 4, the maximum concentration of bacteria and fungi was obtained in the days that $PM_{2.5}$ concentrations were higher, amounting to 252.3 and 504.95 $\mu\text{g}/\text{m}^3$. Studying temporal variability of $PM_{2.5}$ and its associated microorganisms in the central Iberian Peninsula positive correlations between $PM_{2.5}$ and relative humidity, and $PM_{2.5}$ and cultivable microorganisms have been reported (Rodríguez et al., 2020). A consistent trend in the proportion of ambient bacteria and fungi with haze degree during the study were also observed. Water bodies, soil, plants, and anthropogenic activities are recognized as the primary sources of airborne bioaerosols (Xie et al., 2021). Under the unforeseen condition, due to the intense deficit of vegetation and neighbouring to the desert area in Khuzestan, Iraq and Saudi Arabia, episodes of dust storms occur periodically in Abadan (Goudarzi et al., 2014). This behaviour mainly caused bacteria and fungi to attach to the surface of suspended particulate matter. Joen et al. reported that each gram of desert soil may include a large number (about 10^9) of bacterial cells (Jeon et al., 2011). Liu et al. reported that the abundance of pathogenic bacteria was highest in heavily polluted air (Liu et al., 2018). Following our findings, Goudarzi et al. maintained that the greatest bacterial concentrations were observed during dust events compared with normal days (Goudarzi et al., 2014). Also, Li et al. observed the highest value of airborne viable microbes on hazy days and the lowest on rainy days (Li et al., 2017). In contrast, Gao et al. concluded that on hazy days the concentrations of airborne bacteria were low because the compositions of heavily polluted and hazy air might cause damage to the total bacteria (Gao et al., 2015). These findings provide essential information in exposure control programs and health risk assessment, however, further studies are needed to understand the source apportionment, atmospheric diffusion and transport pathways of bioaerosols.

5 Conclusion

In this study, we investigated the relationships between the concentration of culturable airborne bacteria and fungi and meteorological parameters and atmospheric $PM_{2.5}$. The concentrations of airborne bacteria and fungi, as well as the ambient $PM_{2.5}$, were relatively high in the air of the studied area compared to the worldwide similar studies, especially in the cold months. The results indicated that the community of airborne bacteria and fungi were more affected by temperature variation than the other meteorological parameters. Also, it seems to be a significant relationship between the concentration of fungi and relative humidity, while there is no meaningful correlation between bacterial concentration and relative humidity. Moreover, the bacterial and fungal concentrations were significantly correlated to the level of $PM_{2.5}$ concentrations. These findings provide appropriate information for exposure mitigation programs and health risk assessment.

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Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical approval Not applicable.

Consent for publication Not applicable.

Data availability All the necessary data generated or analysed during this study are included in this published article. However, the datasets for statistical analysis are available from the corresponding author on reasonable request.

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