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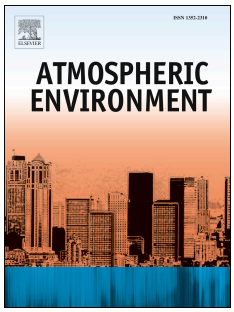

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Impact of Middle Eastern Dust Storms on Indoor and Outdoor Composition of Bioaerosol

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Abstract

The presence of microbes in airborne aerosol particles, especially dust, is a major public health concern in desert regions. This study is the first of its kind to examine the effect of dust storms on indoor and outdoor microbial air quality at a hospital on the western side of Iran (city of Ahvaz), which is notorious for being highly vulnerable to dust emissions. Air samples were collected inside and outside of the hospital environment for six months, with the unique advantage of this study being that the region and duration of measurements allow for a clear comparison between dusty and normal days. On normal days, the average concentrations (outdoor/indoor) of bacteria and fungi were 423/329 cfu m^{-3} and 596/386 cfu m^{-3}, respectively, which increased to 1257/406 cfu m^{-3} and 1116/550 cfu m^{-3} on dust event days. Indoor/Outdoor ratios for bacteria and fungi are lower on dust event days (0.26-0.60) versus normal days (0.44-0.95). *Bacillus spp., Micrococcus spp., Streptomyces spp.*, and *Staphylococcus spp.* were the dominant bacteria both indoors and outdoors on normal and dust event days. Gram positive bacteria exhibited higher concentrations than Gram negative bacteria in both outdoor and indoor air samples as well as during both normal and dust event days. The data suggest that Gram positive bacteria are more resistant to undesirable outdoor conditions (e.g., high incident solar radiation) as compared to Gram negative ones. These results have implications for other populated arid regions where more stringent control of indoor air quality can greatly benefit public health.

Key words: Iran; Aerosol; Bacteria; Dust; Indoor Air Quality; Bioaerosol

1. Introduction

Bioaerosols are an important class of airborne aerosols that can significantly impact public health via pathways such as inhalation and ingestion (e.g., Nasir et al., 2012; Faridi et al., 2015). The impact of these naturally emitted particles extends to climate, cloud formation, and the hydrologic cycle owing to their ability to interact with solar radiation and activate into hydrometeors (e.g., Mohler et al., 2007; Ekstrom et al., 2010). Perhaps the two most important types of bioaerosols are bacteria and fungal spores (e.g., Pastuszka et al., 2000; Mentese et al., 2012), which typically range in diameter between 1-30 µm and 0.25-8 µm, respectively (Gregory, 1973; Thompson, 1981; Jones and Harrison, 2004). Bioaerosols promote infectious diseases, allergy, asthma, and neurological diseases (Chan et al., 2009; Cordeiro et al., 2010). Soil-dwelling fungi can irritate lungs and some reports indicate a relationship between fungi and headaches (Sautour et al., 2007). Mycotoxins generated by fungi can negatively impact human health as they can lead to digestive and respiratory problems (Schlesinger et al., 2006; Sautour et al., 2007, 2009; Cordeiro et al., 2010). Bioaerosols are emitted to the air through different natural and man-made sources such as soil, plants, animals, humans, sewage treatment and agricultural activities (e.g., Hameed et al., 2009); however, the relative importance and characteristics of bioaerosol emissions from these various sources is uncertain.

The impact of a given bioaerosol particle will depend to a large extent on where it deposits upon inhalation. The deposition region depends on particle size and composition, which are linked via the property of hygroscopicity (e.g., Sorooshian et al., 2012). Larger aerosol (D_p > 5 µm) typically impact in the upper parts of the human respiratory system leading potentially to allergic reactions (e.g., Faridi et al., 2015), while smaller aerosol, especially in the sub-

micrometer fraction, can penetrate deeper reaching alveolar regions leading to other adverse impacts.

A better understanding of the composition and concentration of bioaerosols is needed in different parts of the world to develop strategies to minimize their impact on human health, especially indoors where humans spend the majority of their time. There are a different set of factors affecting bioaerosol composition and concentration for indoor versus outdoor environments. For outdoor air, important variables include geographic location, meteorology (e.g., temperature, humidity), density and activity of people, seasonally dependent factors, and plant cover, while for indoor air, important factors include resuspension of dust, indoor pollution sources (e.g., cooking, restrooms, people), plants, temperature, humidity, ventilation, and air conditioning (Hargreaves et al., 2003; Fang et al., 2007; Kim et al., 2009; Mehta et al., 2011; Nasir et al., 2012; Ruzer and Harley, 2012). The relative importance of how each of these factors influences the concentration and chemical signature of bioaerosols is poorly characterized.

Indoor air quality is especially critical in hospital buildings where inhalation of particulate matter can impact the health of its users, crews, and patients who may have vulnerable immune systems (Bouza et al., 2002). Hospital environments include an extensive variety of hazardous materials, such as mixtures of chemical and biological contaminants (e.g., Saad, 2003). Although indoor bioaerosols mostly originate from the ambient atmosphere, they also stem from indoor activities such as with Heating, Ventilation, and Air Conditioning (HVAC) systems (Pastuszka et al., 2000).

A major contributor to reduced indoor air quality in arid and semi-arid regions is dust. Seasonal dust storm activities in the deserts of Asia are most prevalent between February and May (Griffin, 2007). Dust storms in Iran often originate from penetration of high pressure

systems in southern Iraq and northern Saudi Arabia, and are further promoted by drought in these regions. Other factors promoting dust storms include destruction of the groves of Abadan and Khorramshahr in Iran and also the Basra province in Iraq during the Iran-Iraq war (Martiny et al., 2006). Pathogenic and nonpathogenic species in dust-borne microorganisms can be widely distributed via aerosol transport pathways that can potentially change over time (Martiny et al., 2006; Sorooshian et al., 2011; Soleimani et al., 2013; Prabhakar et al., 2014). A classic example is how dust transports the soil-dwelling fungus *Coccidioides Immitis*, which leads to valley fever (Maddy, 1965) in some parts of the world such as the southwestern portions of North America.

Microorganisms in outdoor and indoor air have been studied during dust storms and clear days in numerous regions (Bouza et al., 2002; Griffin et al., 2006; Schlesinger et al., 2006; Chan et al., 2009), but very few studies have characterized the amount of biological material contained in dust that influences the arid region of western Iran, specifically the vulnerable city of Ahvaz, Iran (Goudarzi et al., 2013; Rad et al., 2014). The aim of this study is to, for the first time, survey and compare the concentration and composition of bioaerosols in the indoor and outdoor air of a hospital in Ahvaz, Iran during dusty and normal days. The results have implications for other populated cities in semi-arid and arid regions that cover over a third of the global land area, in addition to providing a valuable set of bioaerosol characterization data to be contrasted with other various regions of the world.

2. Experimental Methods

2.1. Hospital

Measurements were conducted in Golestan Hospital located on the campus of the Ahvaz Jundishapur University of Medical Sciences (see map in Figure 1). This hospital was constructed in 1971 and contains 24 wards and 500 beds. The two areas of focus in the hospital include the Intensive Care Unit (ICU) and selected internal wards, with details for each (e.g., floor area; number of rooms, patients, beds, crew) shown in Table S1 (Supplement). The internal wards cover more than twice the floor area of the ICU (~1200 m^2 versus 540 m^2) with more total rooms (17) and numbers of beds (40). On a representative day in the middle of the sampling period, more patients were observed in the internal wards (~34 versus ~15); however, the ICU had more crew personnel (~25 versus ~22). Patients admitted to this hospital are mainly from Ahvaz and other cities of the Khuzestan province, which has a population of more than 3.2 million people and significantly impacted by dust owing to its location. Past work has shown that dust storms impacting Ahvaz typically originate from the west/northwest/southwest including northern Africa, Iraq, and the Arabian Peninsula (Soleimani et al., 2015).

2.2. Sampling

Air sampling was carried out between September 2010 and March 2011. This sampling period is divided into two seasons: autumn (September – November) and winter (January – March). Sampling days are further categorized as either normal days or dust event days, with the latter based on whether a given sample satisfied any of the conditions for dusty days shown in Table 1 following the criteria defined by Hoffmann et al. (2008). The ICU and selected internal wards were chosen for analysis due to their high density of patients, their significance, hospitalization time period, and higher rates of referrals of people to these wards during dusty days. Since an objective of the study is to compare the concentration and genus of bioaerosols

between indoor and outdoor environments, air samples were collected outdoor of the hospital building at a distance of 4 m from an entry door. Ventilation in hospital rooms is conducted naturally by opening the windows and doors but the windows and doors were closed during sampling.

The strategy used for collecting samples was to obtain one sample every six days for normal days, and one each day on dusty days. Sampling was conducted twice a day at each of the three targeted spots in and out of the hospital at the following times: morning from 09:00-12:00 (Local Time) and afternoon from 16:00-17:00. Indoor and outdoor air samples were collected using a single-stage Anderson sampler with 400 holes (0.25-mm diameter) to draw air over a petri dish containing culture. The air sampling flow rate was 28.3 L min^{-1} and sampling time was two and five minutes for dusty days and five minutes for normal days. The different sampling frequency on dusty days is due to the fact that excessive colony growth complicated measurements when sampling for up to five minutes. Air samples were collected at a height of ~2 m above the ground and a distance of at least 1 m from walls and other obstacles (Sautour et al., 2009).

2.3. Characterization of Biomaterials

Trypticase Soy Agar (TSA) and Potato Dextrose Agar (PDA) were used to cultivate bacteria and fungi, respectively. Cycloheximide and chloramphenicol were added to TSA and PDA, respectively (Kim et al., 2009). TSA and PDA culture plates were prepared as per the manufacturer's instruction and kept in a 37^{o}C incubator for 24 hr. After sampling, fungal cultures were kept at room temperature for 72-96 hrs and bacterial cultures were incubated at 33-37°C for 48-72 hrs (Kim et al., 2009). The concentration of airborne bacteria and fungi were expressed as

the number of colony forming units per cubic meter of air (cfu m^{-3}) by considering the number of colonies counted on the air sample plates, air flow rate and sampling time, and applying the positive hole correction method of Anderson (1958). Genera identification of cultured airborne bacteria was conducted by examination of gram-stained smears and standard biochemical tests according to Bergey's Manual (Kim et al., 2009). Spore staining and acid-fast staining were used to identify Bacillus and Nocardia genera, respectively. Enterobacteriaceae were identified using an Analytical Profile Index (API) kit (Fang et al., 2007).

2.4. Statistical Analyses

The one sample Kolmogorov-Smirnov test is utilized here to examine the normality of the data. Analysis of variance (ANOVA) is used to compare the results obtained for different places on dusty days. The nonparametric equivalence of ANOVA (i.e., Kruskal Wallis test) is employed for the comparison of bioaerosols in different places on normal days. The Mann-Whitney U test and t-test are employed in this study to determine significant differences of bioaerosol concentration between normal and dusty days, and also between seasons. The Spearman's rank correlation coefficient (i.e., a nonparametric measure) is used to quantify the correlation between indoor and outdoor airborne bioaerosol levels during normal and dust event days.

3. Results

The daily mean PM_{10} mass concentration on dust event days in autumn (September - November) and winter (January - March) seasons ranged from 500-1541 μg m^{-3} and 1121-2734

178 μg m^{-3}, respectively. As compared to autumn, higher levels between January and March are
179 partly attributed to a combination of shallower mixing heights (in the earlier part of the winter),
180 and higher wind speeds and more likely transport from upwind desert regions in the latter part of
181 the winter (e.g., Crosbie et al., 2014). Table 2 shows the average concentration of total and
182 dominant bacteria including *Bacillus spp.*, *Micrococcus spp.*, *Staphylococcus spp*., and
183 *Streptomyces spp*. on normal and dusty days. These isolated genera from indoor and outdoor air
184 can cause opportunistic infections and sometimes death (ACGIH 1989). Discussion of data in the
185 two categories of days (normal and dusty) follows below.
186
187 **3.1. Normal Days**
188 Total bacterial concentrations in the outdoor environment were significantly higher than
189 those in the ICU and internal wards during both seasons ($p < 0.05$) (Table 2). Bacterial
190 concentrations were higher in the internal wards as compared to the ICU. Generally, bacterial
191 concentrations in autumn were higher than winter in all sampling areas. There was a significant
192 difference between bacterial concentrations in outdoor air in autumn (average = 458.32 cfu m^{-3})
193 as compared to the winter (average = 392.28 cfu m^{-3}) ($p < 0.05$). However, a significant
194 difference was not observed in indoor air samples when the results of autumn and winter were
195 compared ($p > 0.05$). A significant difference was observed between *Staphylococcus spp.* and
196 *Streptomyces spp.* concentrations in autumn and winter ($p = 0.042$ and $p = 0.03$, respectively).
197 There was also a significant difference between *Streptomyces spp.* concentration in both seasons
198 in indoor air ($p < 0.05$). Panagopoulou et al. (2002) reported summer and autumn as the seasons
199 with the highest concentration of airborne fungi in their studied hospitals in Greece. Similar

results have been reported for airborne bacteria and fungi in Beijing outdoor air and a hospital in France (Kim et al., 2009; Fang et al., 2007).

Table 3 shows the frequency of the identified bacteria on normal and dust event days in all three sampling locations. For normal days, frequencies of detection for dominant bacteria (*Bacillus spp., Micrococcus spp., Streptomyces spp., Staphylococcus spp.*) in indoor and outdoor air were 50.8-93.1% and 82.8-100%, respectively. The frequency that other bacteria in Table 3 were detected in indoor and outdoor air was 0-52.5% and 3.4-71.2%, respectively. *Staphylococcus spp.* and *Bacillus spp.* were the most frequent dominant bacteria in indoor air. *Bacillus spp.* and *Streptomyces spp.* were the most frequent ones in outdoor air. Our results are consistent with those of Fang et al. (2007) and Augustowska and Dutkiewicz (2006), who identified *Bacillus, Staphylococcus,* and *Micrococcus* as dominant bacteria in China and Poland, respectively. In addition to those bacteria, our study shows that *Streptomyces spp.* also was among the dominant bacteria.

The concentration of fungi in indoor and outdoor environments was higher than the concentration of bacteria on normal days, with the difference being largest outdoors (596.62 cfu m^{-3} versus 423.02 cfu m^{-3}) (Table 4). In contrast, the opposite result was obtained in Egypt by Hameed et al. (2009). One of the reasons for higher concentrations of fungi in outdoor air can be the existence of plants and trees on the hospital campus, in addition to other unpaved areas and the exterior surface of the aged hospital that is over 40 years old. Windows of sampled indoor wards were opened and exposed to the outdoor campus environment with a 4 m distance from trees and plants, and thus a higher concentration of total fungi compared to total bacteria in the indoor air could be expected due to transport.

The average amount of bacteria (328 cfu m^{-3}) and fungi (386 cfu $m^{-}3$) in the two indoor hospital areas on normal days exceeded values reported at other sites. For example, estimated airborne fungi levels ranged from 2 to 26 cfu m^{-3} in a French hospital (Fang et al., 2007) and levels of airborne bacteria of 100 cfu m^{-3} were reported in a Polish hospital ward (ACGIH 1989). Our measured concentrations of fungi in outdoor samples (up to 2420 cfu m^{-3}) are higher than those obtained by Sautour et al. (2009) for France (7-23 cfu m^{-3}). In this study, the indoor/outdoor (I/O) ratios for bacteria exceed those for fungi when considering internal wards (0.95 versus 0.86) and the ICU (0.60 versus 0.44).

3.2. Dust Event Days

In contrast to normal days, total bacterial concentrations in all three locations were higher in winter as compared to autumn during dust event days (Table 2). A significant difference ($p < 0.05$) was observed between total bacterial concentration outdoors in autumn versus winter with averages of 812.1 cfu m^{-3} and 1850.5 cfu m^{-3}, respectively. But a significant difference was not observed in indoor air. *Streptomyces spp.* concentrations in both indoor and outdoor environments were higher in the winter than the autumn, but with only a significant difference for outdoor air ($p < 0.05$).

The dominant bacteria (*Bacillus spp., Micrococcus spp., Streptomyces spp., Staphylococcus spp.*) in indoor and outdoor air were measured at frequencies ranging between 78.6-92.9% and 78.6-100%, respectively, which is in the range reported for normal days (Table 3). The frequency that other bacteria in Table 3 were detected in indoor and outdoor air was 0-57.1% and 14.3-64.3%, respectively, which is also similar to normal days. The most frequently detected bacteria in indoor (*Staphylococcus spp.* and *Streptomyces spp.*) and outdoor (*Bacillus*

245 *spp.* and *Streptomyces spp.*) air are similar to normal days, with the exception of *Streptomyces*
246 *spp.* replacing *Bacillus spp.* for indoor air. Average concentrations of fungi in indoor air were
247 higher than bacteria while the opposite was observed outdoors (Table 4). The I/O ratio for fungi
248 in the internal wards were higher than the ratio for bacteria (0.60 versus 0.38), while the I/O ratio
249 for bacteria in the ICU was lower than that for fungi (0.26 versus 0.39).
250
251 **3.3 Diurnal Profiles of PM_{10} and Bioaerosol**
252 Diurnal variations of PM_{10} concentration in the study period for Ahvaz are presented in
253 Figure S1 (Supplement) based on daily collected between September 2010 and March 2011.
254 There is some diurnal structure with minimal concentrations in the early morning (03:00, 199.8
255 µg m^{-3}) and late afternoon (17:00, 183. 1 µg m^{-3}). Maximum levels are reached in the early
256 (~02:00, 236.3 µg m^{-3}) and late morning (~09:00, 241.0 µg m^{-3}). The lack of a smooth
257 concentration profile in the very early morning is likely due to episodic short time scale events.
258 During five dust event days, diurnal data are shown for both PM_{10} and bacteria
259 concentration in Table 5. Regardless of whether PM_{10} is higher during the first or second half of
260 the day, bacteria is also enhanced at that same half of the day in both the Outdoor and Internal
261 Ward areas. The ICU area in a couple cases shows higher bacteria concentrations when PM_{10}
262 was not at its highest; generally speaking based on results already shown in Table 4, the Internal
263 Wards were more reflective of the outdoor air as compared to the ICU. The diurnal data provide
264 support that dust plays an important role to carry and transfer microorganisms between the
265 outdoor and indoor environment. Subsequent discussion provides more support for the link
266 between dust and bioaerosols.

4. Discussion

4.1 Comparison between Normal and Dust Event Days

Compared to normal days, bacteria and fungi concentrations in indoor and outdoor environments on dusty days were significantly higher ($p < 0.05$). On dust event days, bacteria and fungi concentrations in outdoor air samples were higher by factors of approximately three and two, respectively, than those on normal days (Table 4). All four of the I/O ratios for bacteria and fungi reported in Table 4 are lower on dust event days (0.26-0.60) versus normal days (0.44-0.95), due most likely to the overwhelmingly higher concentrations outside on dust event days. For comparison with another city in Iran, specifically Tehran, I/O ratios for bacteria and fungal spores were 1.77 and 1.23 for a retirement home, respectively, and 1.44 and 1.08 for a school dormitory (Faridi et al., 2015).

Figure 2 shows the percentage of concentration of dominant bacteria on normal and dusty days. On normal days, *Staphylococcus spp.* exhibited the highest concentration of bacteria in the ICU (21.2%) and internal wards (30.4%), while *Bacillus spp.* was the most abundant one in outdoor samples (34%). On dusty days, *Bacillus spp.* and *Streptomyces spp.* were significantly enhanced in concentration in both indoor and outdoor air samples ($p < 0.05$); *Bacillus spp.* exhibited the highest concentration in the ICU, internal wards, and outdoor samples, accounting for 21%, 26.8% and 39.1%, respectively.

Figure 3 shows the association between bacterial concentration in both the air of the internal and ICU wards versus that of outdoor air on normal and dust event days. On normal days, the correlation between outdoor bacterial concentrations was higher with internal ward concentrations ($r = 0.67$, $n = 42$) as compared to with the ICU ($r = 0.41$, $n = 42$) (Figure 3). Conversely, for dust event days, outdoor bacterial concentrations were better correlated with the

ICU (r = 0.58, n = 14) as compared to internal wards (r = 0.42, n = 14). The Figure 3 results, especially for normal days, suggest that indoor air quality can be affected by outdoor air quality with regard to bioaerosols. To further support this thought, the highest indoor microbial concentration was recorded in the last month of winter (March) coincident with a dust event lasting two days, showing that dust can affect the concentration and genus of bioaerosols in both indoor and outdoor air. This can partly be explained by the increase in number of patients admitted to the hospital on dusty days, and thus a greater frequency of opened doors and windows to allow for dust to come indoors in addition to patients transporting dust themselves. Thus, the occurrence of dust storms in Ahvaz can affect the indoor air quality of hospital wards both directly, by entrance of dust particles in wards, and indirectly by increase in the patients admitted to hospital.

The number of identified colonies on normal and dusty days is presented in Figure 4. The concentration of bacteria in the most of samples on both normal and dust event days was higher than ACGIH (American Conference of Governmental Industrial Hygienists) standards for indoor air bioaerosols (200 cfu m^{-3}). During normal days, Gram-positive cocci and Gram-positive rods contributed the most in indoor samples with contributions of 44% and 39%, respectively. In outdoor air, Gram-positive cocci and Gram-positive rods contributed 36% and 42%, respectively. On dust event days, Gram-positive cocci and Gram-positive rods contributed 31% and 34% to indoor samples, respectively, and 28% and 39% to outdoor samples, respectively. Gram positive bacteria exhibited the highest concentration in both outdoor and indoor air samples as well as during both normal and dust event days.

4.2 Influence of Ambient Environmental Factors

According to previous investigations, prevailing westerly winds and the fact that Ahvaz is downwind of dust-rich regions such as Iraq, Saudi Arabia and the Sahara Desert, qualify the study region as a major hot-spot for dust storms in the Middle East region (Soleimani et al., 2013; Goudarzi et al., 2014). For example, Soleimani et al. (2015) confirmed with HYSPLIT back-trajectory model data analysis that Ahvaz dust originates from Saudi Arabia, Iraq, and North Africa. High humidity and mild temperature in autumn make the air in Ahvaz a suitable media for bacteria to grow. Gram positive bacteria, which originate from the soil of the aforementioned upwind areas, exhibited the highest percentage (> 90 %) in both indoor and outdoor air on both normal and dusty days, which is similar to the result of other studies (Acea et al., 1988; Augustowska and Dutkiewicz, 2006; Kim et al., 2009). Relative to Gram positive bacteria on normal days, Gram negative bacteria exhibited a higher concentration in indoor air as compared to outdoor air. A likely explanation is that Gram positive bacteria are more resistant to undesirable outdoor conditions (e.g., high incident solar radiation) as compared to Gram negative ones (Zhu et al., 2003). Our results indicate that *Bacillus spp.* exhibits the highest outdoor concentration on both normal and dusty days likely due to their high resistance to undesirable environmental conditions.

5. Conclusions

Dust storms pose a threat for Middle East communities, particularly in Ahvaz on the western side of Iran, which is highly vulnerable to dust transport from upwind regions. Bioaerosols are associated with these dust events and can promote infectious diseases, allergy, asthma, and neurological diseases among vulnerable populations. The focus of this study was to examine bioaerosol concentrations and composition for samples collected inside and outside of

an Ahvaz hospital between September 2010 and March 2011. A unique aspect of this work is the comparison of indoor and outdoor microbial air quality in one of the dustiest regions of the planet with field data spanning multiple months, which allows for a comparison between dusty and normal days.

The data clearly show that bioaerosol (bacteria and fungi) concentrations increased in both indoor and outdoor areas of the hospital atmosphere during dust event days. The dominant bacterial constituents were *Bacillus spp., Micrococcus spp., Streptomyces spp.,* and *Staphylococcus spp.* I/O ratios for bacteria and fungi are lower on dust event days (0.26-0.60) versus normal days (0.44-0.95), due most likely to the overwhelmingly higher concentrations outside on dust event days. The correlation between outdoor and indoor bacterial concentrations was stronger on normal days. But a two day dust event case study in the last month of winter (March) proved that dust can affect the concentration and genus of biomaterials in both indoor and outdoor air. During such dust events, there is an increase in number of patients admitted to hospitals, and thus a greater frequency of opened doors and windows to allow for dust to come indoors in addition to patients transporting dust themselves. Gram positive bacteria exhibited higher concentrations than Gram negative bacteria in both outdoor and indoor air samples as well as during both normal and dust event days. The results also suggest that Gram positive bacteria are more resistant to undesirable outdoor conditions (e.g., solar radiation) as compared to Gram negative ones.

The results of this study motivate artificial ventilation and air conditioning systems instead of natural ventilation in hospitals in dusty regions such as Iran. Using HEPA, ULPA, and HVAC systems to improve indoor air quality in different hospital wards is recommended. Making such changes in hospitals can impact the lives of patients and employees not just in the

359 study region, but many others such as those in other arid regions that cumulatively cover over a
360 third of the global land area.
361
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365

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521 **Table 1**. Dust storm classification as based on the work of Hoffmann et al. (2008).

522

Category	Visibility (m)	Wind speed (m s^{-1})	Hourly averaged PM_{10} (µg m^{-3})
Dusty air	> 2000	-	50-200
Light dust storm (DS1)	< 2000	-	200-500
Dust storm (DS2)	< 1000	> 17	500-2000
Strong dust storm (DS3)	< 200	> 20	2000-5000
Serious strong DS (DS4)	< 50	> 25	> 5000

523

524

525 **Table 2**. Seasonal average concentration (cfu m^{-3}) of four airborne bacteria and total bacteria in
526 outdoor air and indoor units. The number of total samples collected for normal and dust event
527 days was 59 and 14, respectively.

528

		Autumn (Sep - Nov)		Winter (Jan - Mar)	
		Normal	Dust	Normal	Dust
Internal	Bacillus spp.	112.92	120.10	87.61	122.11
Wards	Micrococcus spp.	92.30	101.15	72.70	92.00
	Staphylococcus spp.	133.54	99.41	113.21	97.23
	Streptomyces spp.	47.00	85.30	36.75	96.00
	Other	67.41	64.29	50.76	92.36
	Total bacteria	453.17	470.25	361.03	499.70
ICU	Bacillus spp.	45.00	64.71	47.00	75.00
	Micrococcus spp.	38.70	48.30	56.01	65.00
	Staphylococcus spp.	61.31	72.62	46.23	73.60
	Streptomyces spp.	38.00	48.30	20.10	56.00
	Other	99.38	70.21	56.45	91.23
	Total bacteria	282.39	304.14	225.79	360.83
Outdoor	Bacillus spp.	157.21	325.30	132.40	713.50
	Micrococcus spp.	110.80	143.41	101.91	269.20
	Staphylococcus spp.	45.20	81.40	35.93	90.81
	Streptomyces spp.	80.81	175.60	61.33	364.15
	Other	64.30	86.40	60.71	412.83
	Total bacteria	458.32	812.11	392.28	1850.51

529

530 **Table 3.** Frequency of bacterial genera identification in both indoor and outdoor areas. The
531 number of total samples collected for normal and dust event days was 59 and 14, respectively.

			Frequency (%)		
	Bacteria	Air Type	Internal Wards	ICU	Outdoor
Gram-Positive	Bacillus sp.	Normal	93.1	86.2	100.0
		Dust	85.7	78.6	100.0
	Micrococcus spp.	Normal	72.9	50.8	94.9
		Dust	78.6	85.7	92.8
	Staphylococcus sp.	Normal	93.1	91.4	82.8
		Dust	85.7	92.9	78.6
	Streptomyces spp.	Normal	86.4	81.4	98.3
		Dust	92.8	78.6	92.9
	Corynebacterium spp.	Normal	47.5	42.4	50.8
		Dust	57.1	42.8	50.0
	Rhodococcus spp.	Normal	13.6	6.8	13.5
		Dust	0.0	0.0	35.7
	Micro bacterium spp.	Normal	15.2	8.5	20.3
		Dust	35.7	28.6	50.0
	Stomatoccus spp.	Normal	10.2	8.5	18.6
		Dust	42.9	35.7	50.0
	Arcanobactterium spp.	Normal	0.0	0.0	6.8
		Dust	21.4	0.0	42.8
	Dermabacter spp.	Normal	5.1	0.0	10.2
		Dust	28.6	0.0	42.9
	Brevibacterium spp.	Normal	11.9	0.0	15.3
		Dust	35.7	0.0	42.9
	Deinococcus spp.	Normal	5.1	0.0	13.6
		Dust	14.3	0.0	28.6
	Arthobacter spp.	Normal	8.5	3.4	10.3
		Dust	35.7	14.3	42.9
	Bacillus cereus	Normal	3.4	0.0	8.5
		Dust	21.4	14.3	28.6
	Cellumlomonas spp.	Normal	3.4	0.0	8.6
		Dust	21.4	21.4	35.7
	Nocardiaspp.	Normal	8.4	0.0	13.6
		Dust	28.6	7.1	42.8
	No identification	Normal	50.8	52.5	71.2
		Dust	42.9	50.0	64.3
Gram-Negative	Acinetobacter	Normal	0.0	0.0	5.2
		Dust	0.0	0.0	14.3
	Achromobacter spp.	Normal	8.5	6.8	16.9
		Dust	21.4	0.0	35.7
	Bacillus	Normal	6.8	13.8	20.6
		Dust	3.4	0.0	21.4
	pseudomonas sp.	Normal	15.3	3.4	6.9
		Dust	28.6	14.3	28.6
	Enterobacter spp.	Normal	0.0	0.0	5.1
		Dust	14.3	0.0	21.4
	Seratia spp.	Normal	0.0	0.0	8.5
		Dust	7.1	0.0	28.6
	Klebsiella pneumonias	Normal	5.1	0.0	3.4
		Dust	14.3	0.0	21.4
	No identification	Normal	25.4	28.8	20.3
		Dust	42.8	35.7	50.0

532

533 **Table 4.** Comparison of average concentration and indoor/outdoor (I/O) ratio range for bacteria
534 and fungi (cfu m^{-3}) in both indoor and outdoor air between normal and dust event days. For rows
535 with average concentration data, the range is shown in parenthesis. The number of total samples
536 collected for normal and dust event days was 177 and 42, respectively.
537

		Normal Days	Dust Event Days	p value
Internal	Total Bacteria	403.92 (40-1667)	482.87 (278-808)	0.024
Wards	Total Fungi	510.7 (0-1560)	668.80 (234-988)	0.005
	In/out Bacteria (Fungi)	0.95 (0.86)	0.38 (0.6)	-
ICU	Total Bacteria	252.14 (27-605)	328.44 (148-587)	
	Total Fungi	261.21 (0-998)	431.80 (200-728)	0.035
	In/out Bacteria (Fungi)	0.6 (0.44)	0.26 (0.39)	-
Outdoor	Total Bacteria	423.02 (47-2000)	1257.14 (523-5000)	< 0.0001
	Total Fungi	596.62 (60-2420)	1115.61 (0-1560)	< 0.0001

538

539 **Table 5**. Diurnal variation of PM_{10} and bacteria during dust event days for outdoor air and

540 indoor hospital units.

			Bacteria (CFU m^{-3})		
Date	Time	PM_{10} (µg m^{-3})	Internal Wards	ICU	Outdoor
11/3/2010	AM	123	400	223	785
	PM	536	580	375	938
12/14/2010	AM	562	808	500	1220
	PM	200	380	513	754
12/16/2010	AM	139	560	300	1000
	PM	418	574	176	1530
2/12/2011	AM	277	410	316	923
	PM	427	616	587	5000
3/10/2011	AM	200	560	375	1558
	PM	155	278	411	1092

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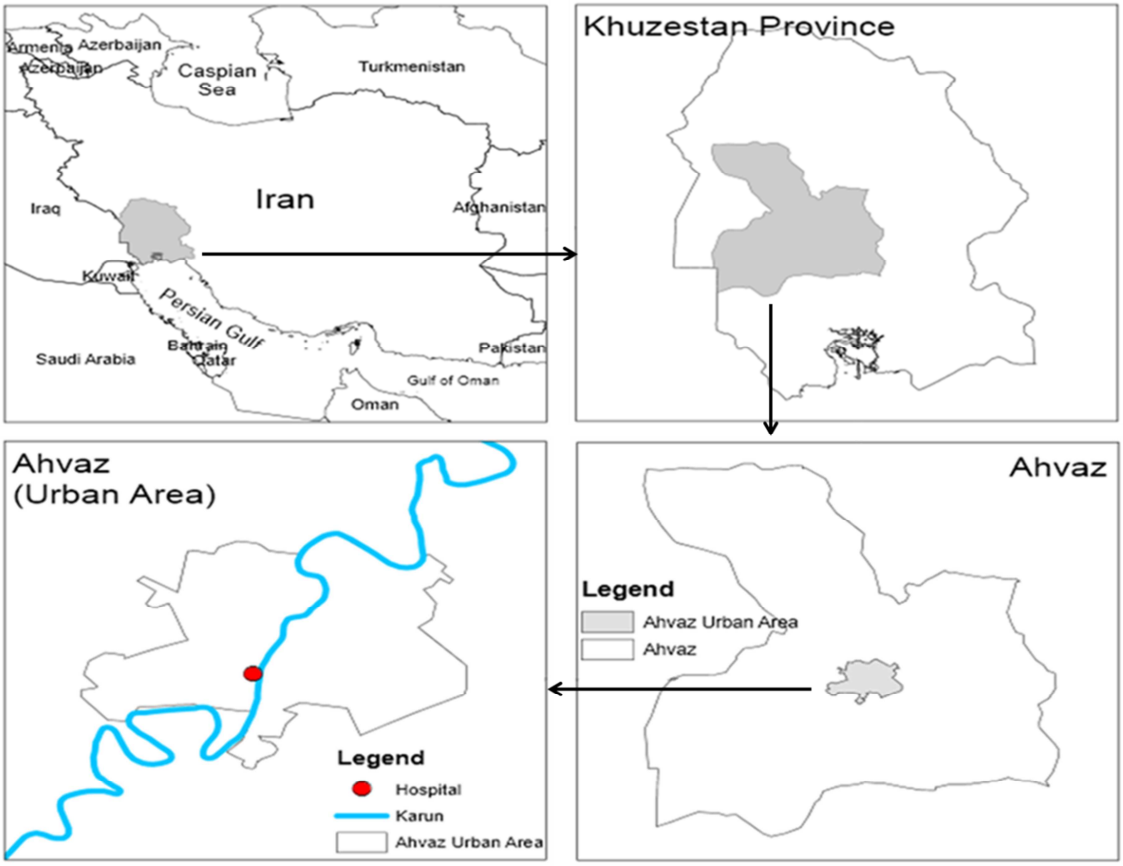
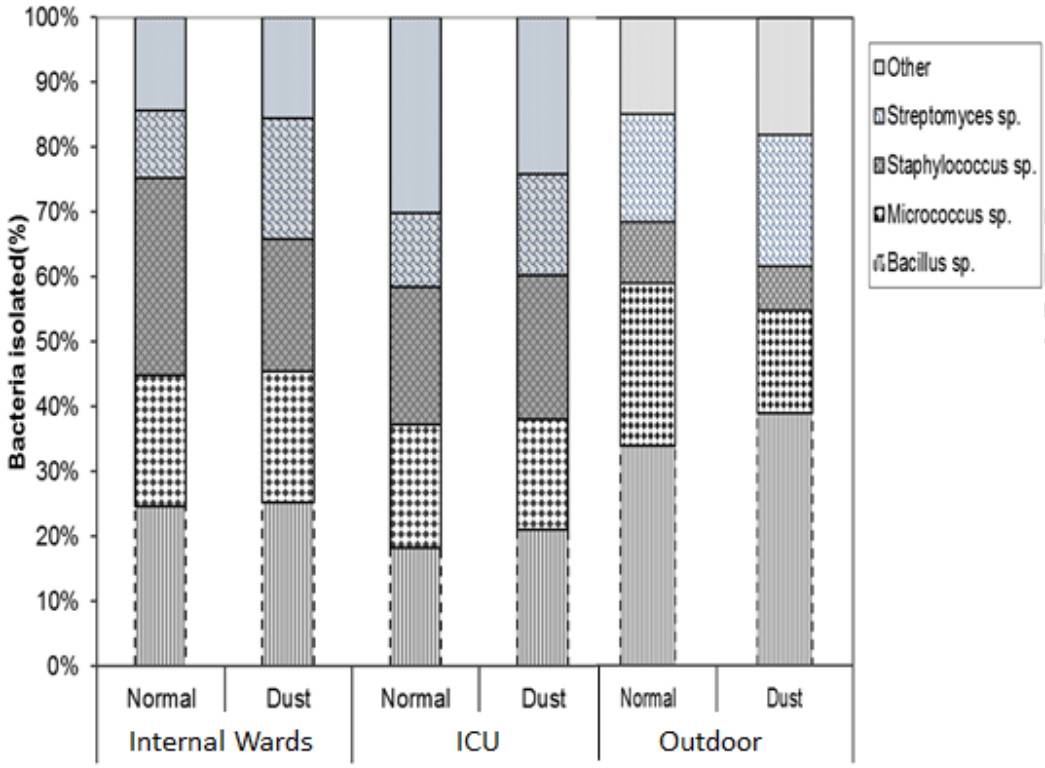


544

545 **Figure 1.** Location of the study area and sampling station. In the bottom left panel, "Karun"

546 refers to a major river.



547

548 **Figure 2**. Percentage contribution of different bacterial species in indoor and outdoor air during

549 normal and dust event days.

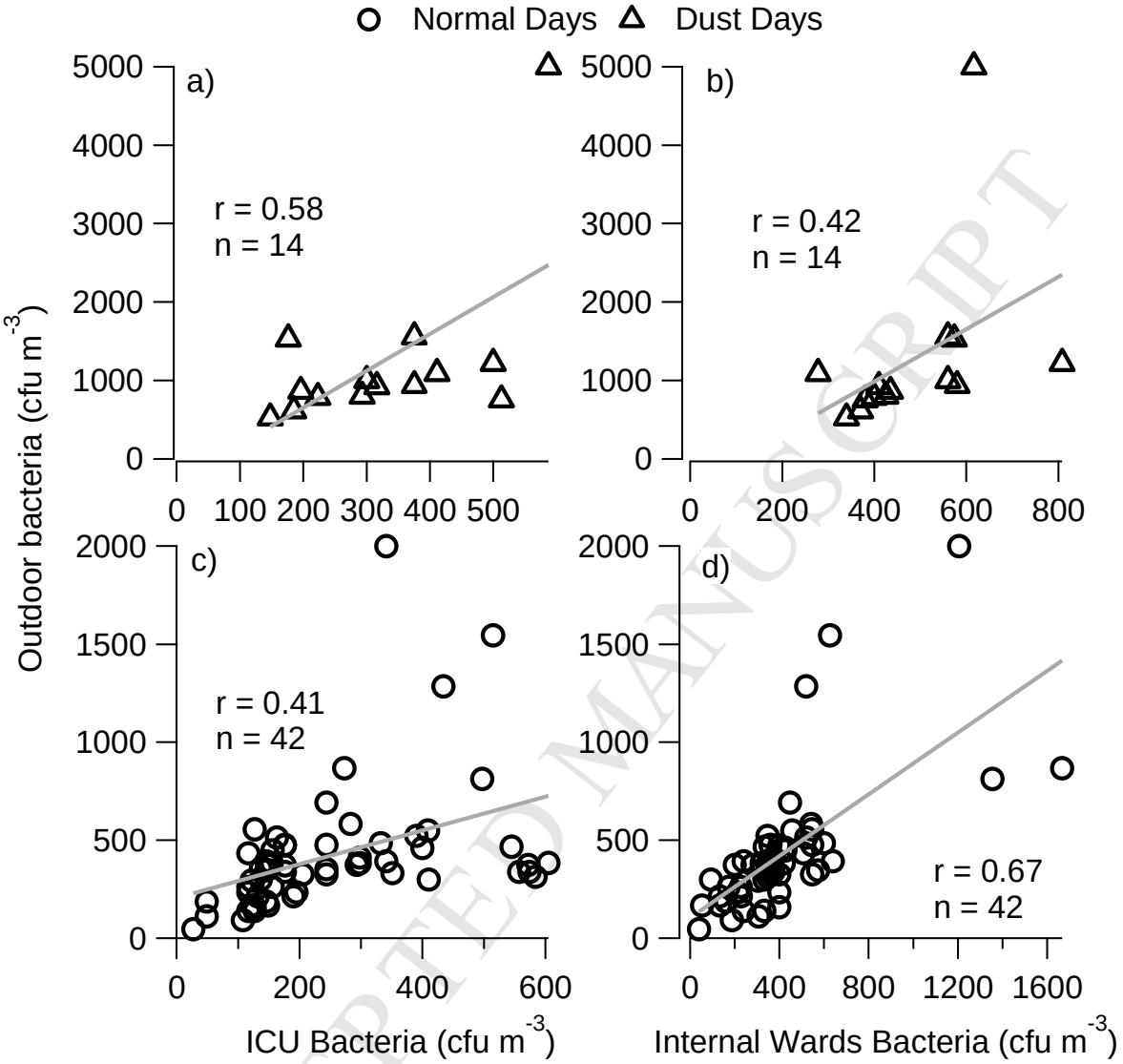
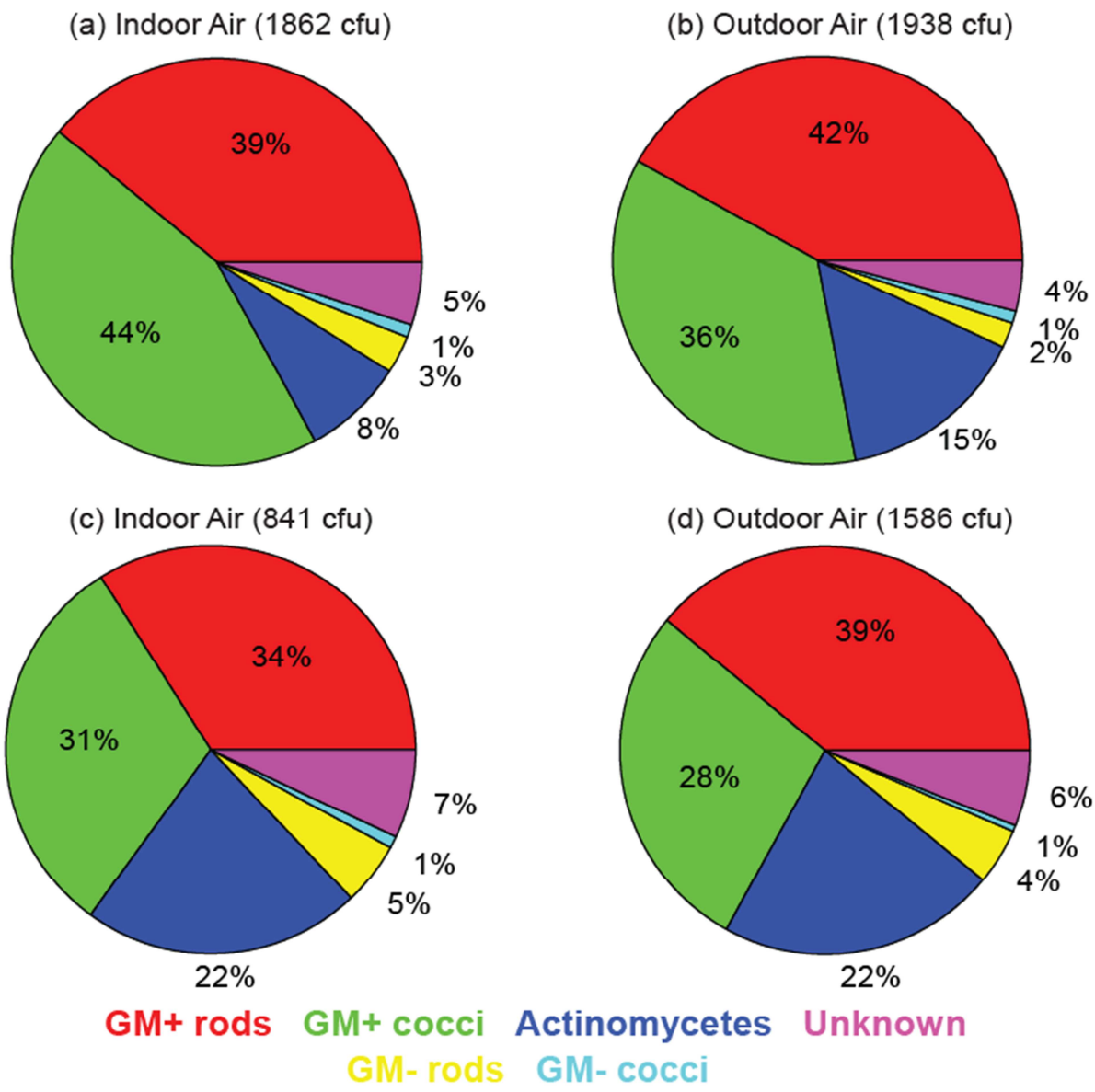


Figure 3. Scatterplot comparing indoor and outdoor airborne bacteria concentration in internal and ICU wards during **(a-b)** dust event and **(c-d)** normal days. Gray lines represent best fit lines with respective correlation coefficients (r) and sample number (n) shown for each panel.



555

556 **Figure 4**. Composition of culturable bacteria in indoor hospital areas and outdoor air during **(a-**

557 **b)** normal and **(c-d)** dust event days. "GM+" and "BM-" refer to Gram positive and Gram

558 negative, respectively.

Highlights:

- Bioaerosol composition measurements in and outside of a hospital in Ahvaz, Iran
- Outdoor bioaerosol are shown to impact indoor hospital air quality
- Bacteria and fungi concentrations higher on dusty days in and out of hospital
- Indoor:outdoor ratios of bioaerosol lower on dusty days (≤0.60) versus normal days
- Gram positive bacteria exhibit higher concentrations than Gram negative bacteria