



OPEN Seasonal evaluation of culturable bioaerosols and airborne particulate matter in Iranian hospital wards using a Monte Carlo health risk model

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This study aimed to measure fine particulate matter (PM) concentrations and culturable bioaerosols (bacteria and fungi) in the indoor air of operating (OR) and emergency (EM) rooms, as well as internal wards (INT) in hospitals in Bushehr city, Iran. For the first time, the Monte Carlo model was employed to assess health risks associated with PM release into hospital indoor air, focusing on healthcare workers. A four-stage impactor and a one-step Anderson contact sampler were used to determine PM and bioaerosols, respectively. To assess the non-cancer risk associated with contaminants (PM), we calculated the Hazard Quotient (HQ). This evaluation was conducted using Crystal Ball software, which performed 1000 independent iterations at a 95% confidence level. The highest PM concentration recorded was 115.6 $\mu\text{g}/\text{m}^3$ in the EM. Based on the results of the Monte Carlo, most calculated hazard quotient (HQ) values exceeded acceptable levels (< 1) for staff. The maximum concentrations of bacteria and fungi were 767 and 776 cfu/m^3 in the EM during summer. A positive correlation was found between fungal levels and humidity in hospital wards. Additionally, PM concentrations of larger sizes and bacteria increased during visiting hours. Most bioaerosol concentrations were above the standard values recommended by WHO. As a result of this study, continuous monitoring and control of indoor air pollutants in these environments are vital to prevent various diseases in healthcare employees and patients.

Keywords PM, Bacteria, Fungi, Indoor air, Hospital, Risk assessment

In recent decades, air pollution has emerged as a significant global environmental issue, particularly in developed countries. The Global Burden of Disease Study in 2012 identified air pollution as one of the top five essential causes of premature deaths, accounting for approximately 3.4 million premature deaths annually worldwide¹. While outdoor air pollution has received considerable attention, indoor air quality (IAQ) is equally crucial as people spend about 87% of their time indoors each day. Therefore, focusing on indoor bioaerosol and particulate matter (PM) emissions is essential for human health, rather than external factors like natural events or outdoor pollution sources². Exposure to high concentrations of indoor air pollutants can lead to a range of health consequences, from acute to chronic effects². Consequently, monitoring indoor air pollutants has become a higher priority than ambient air pollution.

Assessing IAQ in vulnerable environments such as healthcare institutions and hospitals is critical. Hospitals, with their stringent health standards, must provide a safe environment free from health risks for

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patients, clients, and healthcare staff. Poor IAQ in hospitals can lead to increased susceptibility to infections and occupational diseases resulting in various health issues such as Sick Building Syndrome (SBS), reduced work performance, and different symptoms related to unhealthy indoor and outdoor air in buildings, such as headache, irritation, stuffy or runny nose, wheezing, cough, itching, allergic rhinitis^{3,4}. The research involved monitoring PM concentrations (PM₀₁, PM_{2.5}, PM₁₀) and characterizing bioaerosols in the homes of fifty asthmatic patients categorized by house size. Eleven fungal species and seven bacterial species were identified, with higher concentrations of *Alternaria* spp. and *Aspergillus* spp. Linked to asthma occurrence. The highest PM and bioaerosol levels were found in smaller houses, indicating a significant impact of the indoor environment on asthma⁵. Another study investigated the antibiotic resistance of bioaerosols in PM within hospital indoor environments in Dhaka, Bangladesh. The findings highlighted significant antibiotic resistance among bacterial bioaerosols, emphasizing the need for enhanced infection control measures in hospitals, particularly in resource-limited settings⁶. Therefore, monitoring indoor bioaerosol and PM emissions in hospitals is crucial to ensure proper IAQ and protect individuals from potential health hazards.

Bioaerosols and PM are significant pollutants in hospitals due to infectious patients, various human activities, and inadequate ventilation⁷. PM exposure poses more health risks to sensitive groups such as children (less than 15 years old), the elderly (over 65 years old), and individuals with weak immune systems (patients in hospitals)^{8,9}. Studies have shown a link between exposure to PM in indoor air and increased respiratory infections in children, patients, and vulnerable populations^{10,11}. In a study by Smith et al., they found that the increase in PM in indoor air causes more incidence of acute respiratory infection and pneumonia in children under 2 years old¹². The extent of PM effects on human health is largely dependent on their size. PM less than 2.5 µm in diameter (PM_{2.5}) is more widely investigated in studies due to its greater association with adverse health effects on humans. A study aimed to determine the relationship between PMs and bioaerosols in pediatric ICU, neonatal ICU, and ICU open heart units at Shahid Beheshti Hospital in Kashan, Iran. The research was conducted over 6 months during the autumn and winter of 2021. The results showed that the maximum PM₁₀ concentration was 59.19 µg/m³ in the PICU, and the maximum PM_{2.5} concentration was 20.23 µg/m³ in the NICU. Gram-positive *Staphylococcus* was the most abundant bacteria (90.96%), and *Aspergillus*, *Penicillium*, and *Cladosporium* were the dominant fungi¹³. Fouladvand et al. (2024) investigated the relationship between bioaerosols and PM_{2.5} and PM₁₀ in liver transplant operating rooms at Imam Khomeini Hospital in Tehran. The results showed average PM_{2.5} and PM₁₀ concentrations of 17.8 and 27.0 µg/m³, respectively. Bacterial bioaerosols were strongly correlated with PM concentrations, while the relationship with fungal bioaerosols was weaker. The study highlights the importance of monitoring indoor air quality in healthcare settings to prevent disease transmission¹⁴. A study showed that bacterial bioaerosol concentrations were significantly correlated with PM levels. The study highlighted the importance of maintaining good indoor air quality in healthcare settings to prevent infections and ensure patient safety¹⁵. One of the most common diseases that patients with weak immune systems get involved in hospitals is secondary hospital infections. PM with different sizes (nanometers to micrometers) can provide suitable conditions for the transfer and entry of microbial and biological factors such as bacteria, viruses, and fungi from the ambient air into the body and cause an increase in infection in patients^{16–19}. Also, bacterial, viral, and fungal infections are often caused by inhalation and ingestion of these agents along with PM, which include Aspergillosis and pneumocystis²⁰.

Bioaerosols, comprising living aerosols like bacteria, viruses, and fungi, are sourced from various sources in hospitals, including infectious secretions, materials, and equipment, as well as ambient air^{21–23}. Bioaerosols can cause a range of diseases in humans, including infectious diseases, cancer, respiratory diseases, asthma, and allergies^{24–26}. It indicates that determining bioaerosols in the indoor air of healthcare organizations is crucial. The scientific and research gap in this area primarily revolves around the insufficient focus on IAQ in healthcare facilities, despite its critical role in preventing infections and ensuring the safety of patients and staff. While outdoor air pollution has been extensively studied, limited attention has been given to the impact of indoor bioaerosols and PM on health, particularly in hospital environments where vulnerable populations are present. Additionally, there is a need for more targeted studies on the relationship between PM and bioaerosols in specific hospital units, such as intensive care or operating rooms, and their health implications for sensitive groups like children, elderly patients, and immunocompromised individuals. Addressing these gaps through systematic monitoring and advanced modeling approaches, such as Monte Carlo simulations, can provide a deeper understanding of IAQ dynamics and inform effective infection control measures.

Thus, this study investigated PM, and bioaerosols (bacterial and fungal) in the selected hospitals' indoor air from Bushehr City during different seasons, in Iran. To the best of our knowledge, there has been no report yet on the PM size-fractionated and culturable bacteria and fungi in Bushehr's hospital indoor air during different seasons. The study focused on the operation room (OR), emergency (EM), and internal ward (INT) and assessed the effects of visiting time on PM and bioaerosol concentrations in the INT ward. Additionally, the study employed a Monte Carlo model to evaluate the health risks associated with PM release in various hospital wards, considering both staff and patients.

Materials and methods

Study area

This analytical-cross-sectional study was performed on the different hospital wards from Bushehr City, Iran, from April 2023 to March 2024. In the present study, two hospitals in Bushehr City (Fig. 1) were selected for sampling after the feasibility studies were carried out. Bushehr City, located in the southwest of Iran and the Middle East region, was selected for sampling due to its long hot seasons, geographical location, the presence of various industries and seasonal storms, and the lack of studies in the field of measuring PM and bioaerosols in the hospitals' indoor air (Table 1).

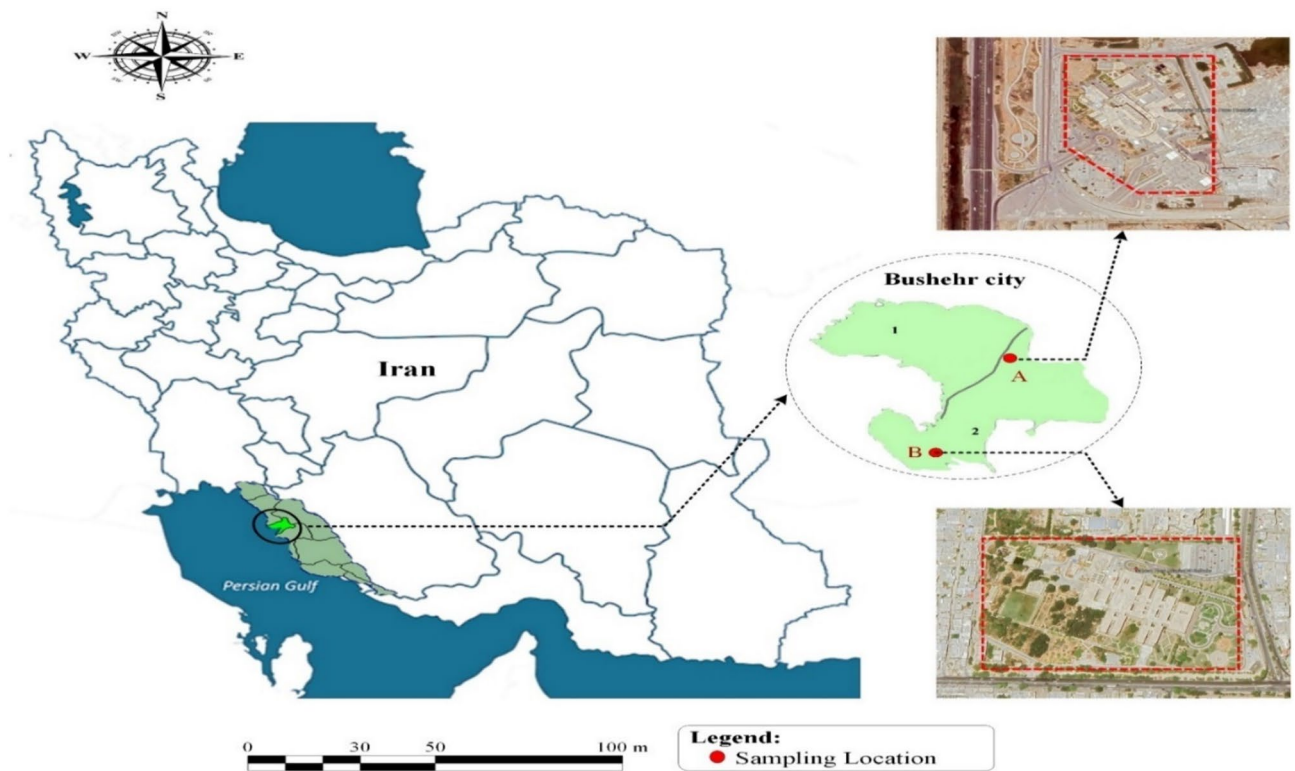


Fig. 1. Location of sampling sites (Hospital A and B) within Bushehr City, Iran [Google Earth Pro, Visio: version 2502].

Air pollution sampling

Hospital and ward selection

The PM and bioaerosols (bacteria and fungi) concentrations were investigated in two selected hospitals' indoor air (one for specialized use and the other one for general use) during different seasons. Sampling was conducted across three selected wards—OR, EM, and INT—based on their importance for assessment, patient health status, length of patient stays, and feasibility of sampling. Sampling sites A and B were chosen based on some criteria including the number of clients, geographical location, traffic density, and urban commuting patterns. Based on these criteria, two main hospitals from two different section of this city were chosen. Site A was chosen in a high-traffic urban zone, city entrance, adjacent to a major highway, while site B is a mixed residential-commercial area with moderate footfall (Fig. 1).

Sampling methodology

Sampling was performed twice per season in each ward, with additional sampling in the INT ward before and during visiting hours (15:00–16:00) to evaluate the effect of population density on PM and bioaerosol concentrations. A total of 64 PM sampling sessions were conducted throughout the year to capture seasonal variations, with results averaged over an 8-h workday for comparison with the American Conference of Governmental Industrial Hygienists (ACGIH) existing standards. Bioaerosol sampling involved two repetitions per ward on each sampling day, resulting in 128 bacterial samples and 128 fungal samples collected across all wards during the study. This approach ensured an accurate representation of real conditions while reducing contamination on plates and improving colony distinction. Bioaerosol samples were collected simultaneously with PM samples to maintain consistency.

Environmental parameter measurement

Temperature, pressure, and environmental humidity were recorded at the beginning and end of PM and bioaerosol sampling, and the average was reported in this study (Letus, PHB-318).

PM measurement

The PM sampling in this study was carried out by using active sampling and gravimetric methods based on the ISO-16000-37 standard method²⁷. PM samples were collected by air pumping (9 L/min) through a four-stage impactor (Sioutas Cascade, SKC) with a size-selective inlet ($PM_{1-2.5}$, $PM_{0.5-1}$, $PM_{0.25-0.5}$, and $PM_{<0.25}$ μm) which was included the fiberglass filter with a diameter of 37 mm (SKC, type AE-250). Due to the existing restrictions for attendance in the wards, including the operating room, a pre-test was conducted to determine the duration of sampling. Therefore, 4 h of sampling time was chosen. Before and after sampling, filter paper was placed in a desiccator for 24–48 h to dehumidify and then weighed (AB204-N scale model). The sampling device was

City	Population	Area (Km ²)	Average temperature (°C)	Annual relative humidity (%)	Average yearly rainfall (mm)	Elevation (m)	Hospital	Inpatient Bed Occupancy Rate (%)	Inpatient bed count	Usage	Ward	Floor	Air conditioning system
Bushehr	223,504	50	27	53.4–75.4	117.5	18	A	90	200	Educational specialty and subspecialty	Emergency room Operation room	G ^a 2nd 1st	Natural Combined Mechanical
							B	~ 100	186	Non-educational general	Emergency room Operation room	G G 1st	Mechanical Combined Mechanical

Table 1. Description of the sampling locations in the different wards of selected hospitals. ^aGround.

placed at the breathing height (1.3–1.5 m) and at a point that represented all indoor air of the wards, including the nursing station (Fig. 2).

Finally, PM concentration has been calculated through the following equation:

$$C = \frac{W_2 - W_1}{V} \times 10^6 \quad (1)$$

In the mentioned equation, C is the PM concentration ($\mu\text{g}/\text{m}^3$), W_1 and W_2 are the primary and secondary filter weights, respectively (before and after sampling), and V is the passing air volume through the filter during the sampling period (m^3).

Also, the PM values were calculated over 8 h to compare the obtained PM concentrations in the hospital indoor air during sampling (4 h) with the existing standards, by using the following equation:

$$TWA = \frac{C_1 t_1 + C_2 t_2}{T} \quad (2)$$

TWA is the time-weighted average ($\mu\text{g}/\text{m}^3$), C_1 and C_2 are the PM concentration in each sampling duration ($\mu\text{g}/\text{m}^3$), t_1 and t_2 are the duration of sampling (hr), and T is the exposure time related to standard (8 h).

Monte Carlo simulation

An individual exposure assessment pertains to the level of exposure to inhaled pollutants, which is determined through on-site monitoring of hazardous substance concentrations and an analysis of the duration and routes of exposure. Currently, comprehensive studies on human exposure parameters in hospital wards concerning PM and bioaerosols are lacking. Therefore, it is crucial to compile existing literature related to these exposure parameters. Subsequently, the USEPA risk assessment model was utilized to convert the PM concentrations measured on-site into the average daily exposure dose (ADD) for workers using a specific equation^{28,29} (3):

$$ADD_{\text{inhalation}} = \frac{C \times IR \times ED \times EF \times ET}{BW \times AT} \quad (3)$$

where ADD represents the average daily exposure concentration for workers ($\text{mg}/\text{kg}\cdot\text{d}$), C denotes the cumulative PM concentration around the hospital wards (mg/m^3), IR indicates the inhalation rate of an adult (m^3/h), ED reflects the exposure duration (years), EF signifies the exposure frequency (days/year), ET describes the exposure time (h/day), BW is the body weight (kg), and AT represents the average time (days). Human exposure parameters for health risk assessment, including inhalation rate, body weight (for adults), exposure duration, frequency, and average exposure time, were collected from relevant literature sources. The gathered data were analyzed using Crystal Ball software (Oracle Crystal Ball, Version 11.1.2.4) with 1000 iterations of independent runs at a 95% confidence level for data entry and statistical analysis. The final results are presented in various formats; however, this paper emphasizes key outputs such as the forecast chart, percentiles summary, and statistics summary. Larger absolute values signify a greater impact on risk. The parameter distributions were determined based on related literature^{30,31} and summarized in Table 2.

To evaluate the non-cancer risk associated with contaminants (PM), we computed the Hazard Quotient (HQ), defined as the ratio of the $ADD_{\text{inhalation}}$ to the reference dose for chronic exposure (RfD), expressed in $\text{mg}/\text{kg}\cdot\text{day}$, as shown in the equation³² (4):

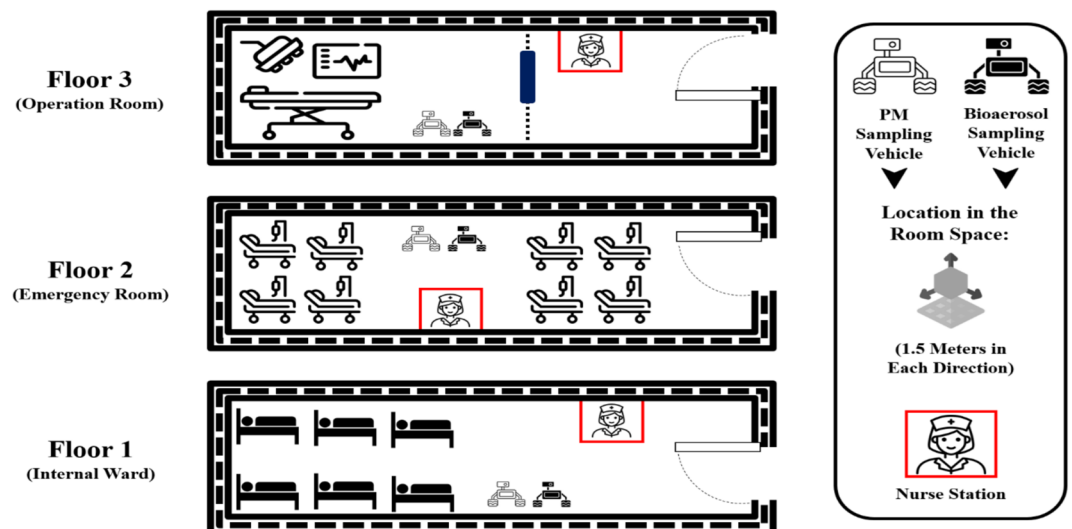


Fig. 2. PM and bioaerosols sampling locations in different hospital wards (OR, EM, and INT wards).

Parameters	Unit	Distribution	Min	Mode	Max	SD
IR	m ³ /h	Triangular	0.95	1.9	2.85	–
ED	year	Triangular	5	30	45	–
EF	day/year	Triangular	60	330	345	–
ET	h/day	Triangular	6	7.5	8	–
BW	kg	Normal	42.1	–	71.6	5.8
AT	day	Triangular	1825	10,950	16,425	–

Table 2. Parameters to consider for the PM Monte Carlo simulation (adults).

$$HQ = \frac{ADD}{RFD} \quad (4)$$

If the *HQ* is greater than 1, it suggests a potentially significant risk; conversely, an *HQ* of 1 or less indicates that the non-carcinogenic risk associated with PM is at an acceptable level. Additionally, the *RFD* can be calculated using the following Eq. (5).

$$RfD = \frac{RfC \times IR}{BW} \quad (5)$$

Due to insufficient information regarding the *RfC* for cumulative PM, this study used an *RfC* of 5 µg/m³ for particles to calculate the *RfD* for PM^{4,33}.

Bioaerosol analysis

Bacteria and fungi are among the main sources of hospital infections that cause most diseases and deaths³⁴. Therefore, in this study, the bacteria and fungi contents have been investigated in the indoor air of the OR, EM, and INT selected hospital wards. The NIOSH-0800 standard method was applied to sample bioaerosols (bacteria and fungi) in the indoor air of different wards³⁵. Based on this method, the one-step Anderson contact sampler (Quick take 30) was used with a flow rate of 28.3 L/min for 10 min. To determine bacterial and fungal colonies separately, air samples have been through from a plate containing Tryptic Soy Agar (TSA) (Merck, Germany) and cycloheximide antibiotic (to prevent fungal growth) and Malt Extract Agar (MEA) (Merck, Germany) and chloramphenicol antibiotic (to prevent bacterial growth), respectively. The sampler was sterilized before sampling with 70% alcohol and placed at the breathing height of the people (1.3–1.5 m) (Fig. 2). Also, with each sampling series, a plate containing bacteria or fungi culture medium was placed next to the sampling device as a control sample. The control sample indicates the presence of possible contamination in the cultivation medium during sampling. The difference between the contamination in the main sample and the control is reported. After sampling, the plate containing the medium culture was placed in a cold box sterilized with alcohol and transferred to the laboratory for cultivation and colony counting. Then, the plates containing TSA medium culture were placed in an incubator at 35–37 °C for 24–48 h to grow bacterial colonies. Also, the plate containing MEA medium culture has been kept at 25–27 °C temperature for 5–7 days in the laboratory environment and under suitable conditions. The colonies formed on the medium culture were counted by the colony counter device (model scan100-Interscience). Finally, the average load of bacterial and fungal sampled in both sampling series in the indoor air of different hospital wards in each season has been reported based on the following equation (cfu/m³):

$$\frac{CFU}{m^3} = \frac{1000 \times P}{T \times Q} \quad (6)$$

In Eq. (6), *P* is the number of colonies counted in each plate, *Q* is the flow rate of the sampling pump (L/min), and *T* is the sampling time (min).

Statistical analysis

Statistical analysis was investigated in this study by Minitab 21 statistical software. The correlation between PM and bioaerosols concentrations with meteorological conditions (i.e., temperature, relative humidity) was carried out by the Pearson correlation coefficient in various departments of a hospital during different seasons (*P* < 0.05).

Results and discussion

PM concentration

The mean (±SD) concentrations of PM in different hospital wards over each season in Bushehr City, Iran are reported in Table 3. Based on the importance of PM size distributions in hospital indoor air, the four PM sizes including PM_{1–2.5}, PM_{0.5–1}, PM_{0.25–0.5}, and PM_{<0.25} were considered and sampled in this study. The PM concentration range in hospital A was 9.1 and 115.6 µg/m³ in the INT ward and EM room during summer for PM_{<0.25} and PM_{1–2.5}, respectively. The lowest and highest PM concentrations in hospital B were 9.2 and 69.5 µg/m³ neither in the OR nor EM room for PM_{<0.25} during summer and spring, respectively. Although no standard has been stated based on the PM size fractions measured in this study, based on the recommended standard values of the 8-h average PM concentration in indoor air including hospitals by ACGIH (PM_{2.5} = 3 mg/m³, and

Hospital	Ward	PM concentration (µg/m ³)																							
		Spring						Summer						Autumn						Winter					
		PM _{1-2.5}	PM _{0.5-1}	PM _{0.25-0.5}	PM _{<0.25}	PM _{1-2.5}	PM _{0.5-1}	PM _{0.25-0.5}	PM _{<0.25}	PM _{1-2.5}	PM _{0.5-1}	PM _{0.25-0.5}	PM _{<0.25}	PM _{1-2.5}	PM _{0.5-1}	PM _{0.25-0.5}	PM _{<0.25}	PM _{1-2.5}	PM _{0.5-1}	PM _{0.25-0.5}	PM _{<0.25}				
A	Mean	22.8	34.2	91.3	68.5	34.4	34.6	46.2	18.6	34.1	34.1	22.7	11.3	22.5	33.8	56.3	22.5	22.5	33.8	56.3	22.5				
	SD	0.0	16.1	96.8	96.8	15.9	16.6	33.0	32.8	16.1	16.1	32.1	16.0	0.01	16.0	15.9	31.9	0.01	16.0	15.9	31.9				
	Mean	45.5	45.5	34.1	45.5	115.6	104.0	34.4	18.6	56.8	34.0	45.4	22.7	79.5	45.4	11.3	11.4	79.5	45.4	11.3	11.4				
	SD	0.0	0.0	16.1	32.2	131.3	114.9	15.8	0.5	48.2	16.0	32.2	0.03	47.8	31.9	16.0	16.1	47.8	31.9	16.0	16.1				
	Mean	34.2	68.4	34.2	22.8	45.8	22.9	18.3	9.1	68.2	45.4	45.4	34.0	78.9	22.5	11.3	35.1	78.9	22.5	11.3	35.1				
	SD	16.1	96.7	16.1	32.2	32.5	0.05	32.3	16.2	64.5	0.2	0.2	16.0	47.6	0.1	15.9	16.0	47.6	0.1	15.9	16.0				
B	Mean	34.7	11.6	34.7	69.5	46.1	23.1	23.0	9.2	22.8	34.1	22.8	22.8	45.2	22.6	11.2	NDa	45.2	22.6	11.2	NDa				
	SD	16.4	16.4	16.4	65.5	32.5	0.1	32.6	16.3	0.1	16.0	0.01	16.3	32.1	0.14	15.9	ND	32.1	0.14	15.9	ND				
	Mean	34.7	11.6	34.7	69.5	69.1	46.1	34.6	9.2	34.0	56.9	34.0	22.7	11.3	22.7	45.4	68.1	11.3	22.7	45.4	68.1				
	SD	98.1	0.0	0.0	16.3	0.1	32.6	16.3	16.3	15.9	48.5	48.0	0.1	16.0	0.1	32.3	64.4	16.0	0.1	32.3	64.4				
	Mean	11.6	34.7	34.7	ND	57.5	46.0	23.0	34.5	56.6	34.0	22.7	11.3	90.6	45.3	ND	35.1	90.6	45.3	ND	35.1				
	SD	16.3	16.3	16.3	ND	16.5	0.2	0.1	16.4	15.7	16.2	32.2	16.1	64.2	32.1	ND	16.0	64.2	32.1	ND	16.0				

Table 3. PM concentration in the different hospital wards. ^aNon-detected.

$PM_{10} = 10 \text{ mg/m}^3$)^{36–38}, all PM concentrations in this study had been lower than this standard. Accordingly, the PM concentration in different sampling wards in the selected hospitals in this study can cause various health effects for the healthcare employer in these wards in the long term. Based on the results, the highest PM concentration was observed in the EM room of hospital A during summer for the largest PM size distribution ($PM_{1-2.5}$). It can cause high and uncontrolled traffic of clients, high workload and special human activities of this ward, and also lack of proper ventilation systems. In addition, cleaning activities, and opening doors, and windows in different wards can resuspend PM and change their contents in indoor air. However, the PM concentration with a smaller size distribution ($PM_{0.25-0.5}$ and $PM_{<0.25}$) in the OR room during spring and summer was higher than that of other wards in both hospitals. This result can be due to the hot weather conditions during these two seasons in this city and also the use of mechanical ventilation including air conditioners in the OR compared to other seasons, which increases the possibility of moving particles with smaller sizes. A study was done to assess the effects of different ventilation systems on the IAQ in different hospital wards in Taiwan. The results of this study demonstrated that the $PM_{2.5}$ and PM_{10} concentrations were higher at the hospitals with non-central air conditioning systems³⁹. Generally, PM contents were higher in Hospital A compared to the hospital B. Hospital A is the main Bushehr governmental hospital which is a bigger, educational and specialty and subspecialty hospital, close to the main entrance streets of the city, and also it has lots of clients and patients compare to the other hospital. The PM concentrations had different trends during seasons although it was higher in summer than that during other seasons. Also, the results showed that the $PM_{1-2.5}$ concentration was higher in different wards compared to the other PM size distribution. In a study, Mohammadyan et al. investigated the PM_1 , $PM_{2.5}$, and PM_{10} in two hospitals during 3 months in Kashan, Iran. The results of this study also showed which mean PM indoor concentrations were higher in larger PM content ($PM_{10} = 162.7 \text{ } \mu\text{g/m}^3$) compared to the smaller size of particles ($PM_1 = 17.8 \text{ } \mu\text{g/m}^3$, and $PM_{2.5} = 45.5 \text{ } \mu\text{g/m}^3$) in different wards⁴⁰. PM in indoor air originates from various sources totally the probability of PM diffusion and settling with larger sizes is higher. However, the presence of PM with small sizes (0.25 μm) in hospital indoor air has also detrimental effects because patients with low health levels are present in the hospital. The PM health rate consequences in different age groups especially for sensitive groups with low immunity levels depend on the originating sources⁴¹. In addition, the PM effects on human health depend on other characteristics, including the PM size distribution and secondary compounds such as chemical composition which are transmitted to the human body⁴². Based on the results of studies, PMs with different size distributions can enter different parts of the lung, which is particles with smaller sizes can penetrate deeper lung areas and cause more health effects^{43,44}. In most studies, with the purpose of PM evaluation in hospital wards, just were determined the PM_1 , $PM_{2.5}$, and PM_{10} concentrations. A study was carried out by Heibati et al. and the results showed the mean PM_1 , $PM_{2.5}$, and PM_{10} concentrations of different Shiraz hospital wards during winter 0.7, 4.7, and 38.7 $\mu\text{g/m}^3$, respectively⁴⁵. In another study, that was conducted in the dentistry clinic at Athens University, contrary to the results of the present study, higher amounts of particles were reported ($PM_{2.5} = 23\text{--}229 \text{ } \mu\text{g/m}^3$, and $PM_{10} = 33\text{--}326 \text{ } \mu\text{g/m}^3$)⁴⁶. In addition to the determination of pollutants in hospital wards, various studies have also investigated pollutants in indoor air of other environments. In another study, Martins et al. (2020) investigated children's exposure to PM ($PM_{0.25}$, $PM_{0.25-0.5}$, $PM_{0.5-1.0}$, $PM_{1.0-2.5}$, and $PM_{2.5-10}$) and different chemical compounds in the indoor air of schools and homes in Lisbon, Portugal. Based on the results of this study, children in schools (33.0–97.2 $\mu\text{g/m}^3$) have been exposed to a higher concentration of particles compared to homes (10.8–37.7 $\mu\text{g/m}^3$). Also, in line with the results of the present study, it has been shown that particles with larger sizes ($PM_{2.5-10}$) were found higher (9.4–56.1 $\mu\text{g/m}^3$) in indoor environments, including schools and homes⁴⁷. It should be noted that in addition to PM, there is a possibility of other pollutants in the indoor air, including bioaerosols and various chemical compounds⁴⁸. Therefore, the presence of various pollutants in the indoor air of hospitals causes various respiratory diseases in the employees. Asthma, shortness of breath, and cough are common diseases among healthcare workers, which have been reported in various studies^{49,50}. The results of a study in American hospitals showed that there is a significant relationship between the $PM_{2.5}$ concentration in the indoor air and the risk of patient death⁵¹. Although the concentration of various biological and chemical compounds bound to PMs also influences the amount of health effects. Also, the identification of chemical compounds transmitted through PM can determine the particle-emitted resources, which ultimately can be considered the necessary control ways to prevent PM emission.

PM health risk assessment

The PM concentration probability distribution was mainly modeled through Crystal Ball software. The lognormal distribution was identified as the most suitable fit for PM concentration data in this study. The results of the PM health risk simulation across various wards in two selected hospitals are illustrated in Fig. 3. Airborne PM in OR, EM, and INT wards can lead to multiple health effects for workers. Most of the HQ values presented in Fig. 3 surpassed the standard threshold (greater than 1), indicating potential health risks for employees in these wards. The highest average HQ value (7.45) was associated with the A-EM, likely due to increased PM concentrations within the activities. Thus, the concentration of PM can be served as the most critical input parameter in the Monte Carlo model. According to studies conducted so far, a Monte Carlo model has not been used to determine the health effects of PM in the indoor air of hospital wards for healthcare workers; although based on the studies, Barkhordari et al. examined the health risks of PM_{10} , $PM_{2.5}$, and PM_1 emitted from a waste sorting facility, finding HQ values ranging from 0.126 to 5.561, which were lower than those reported in this study⁵².

Investigation effects of visiting time on the PM concentration

One of the purposes of this study was to investigate the effect of the visiting time in the INT ward on the PM concentration before and during it. According to the results of this study, the PM contents during the visiting hours were higher than before that of most sampling days, especially in spring and summer in both hospitals. The highest PM concentration in the INT ward during visiting time was related to the $PM_{1-2.5}$ fraction in

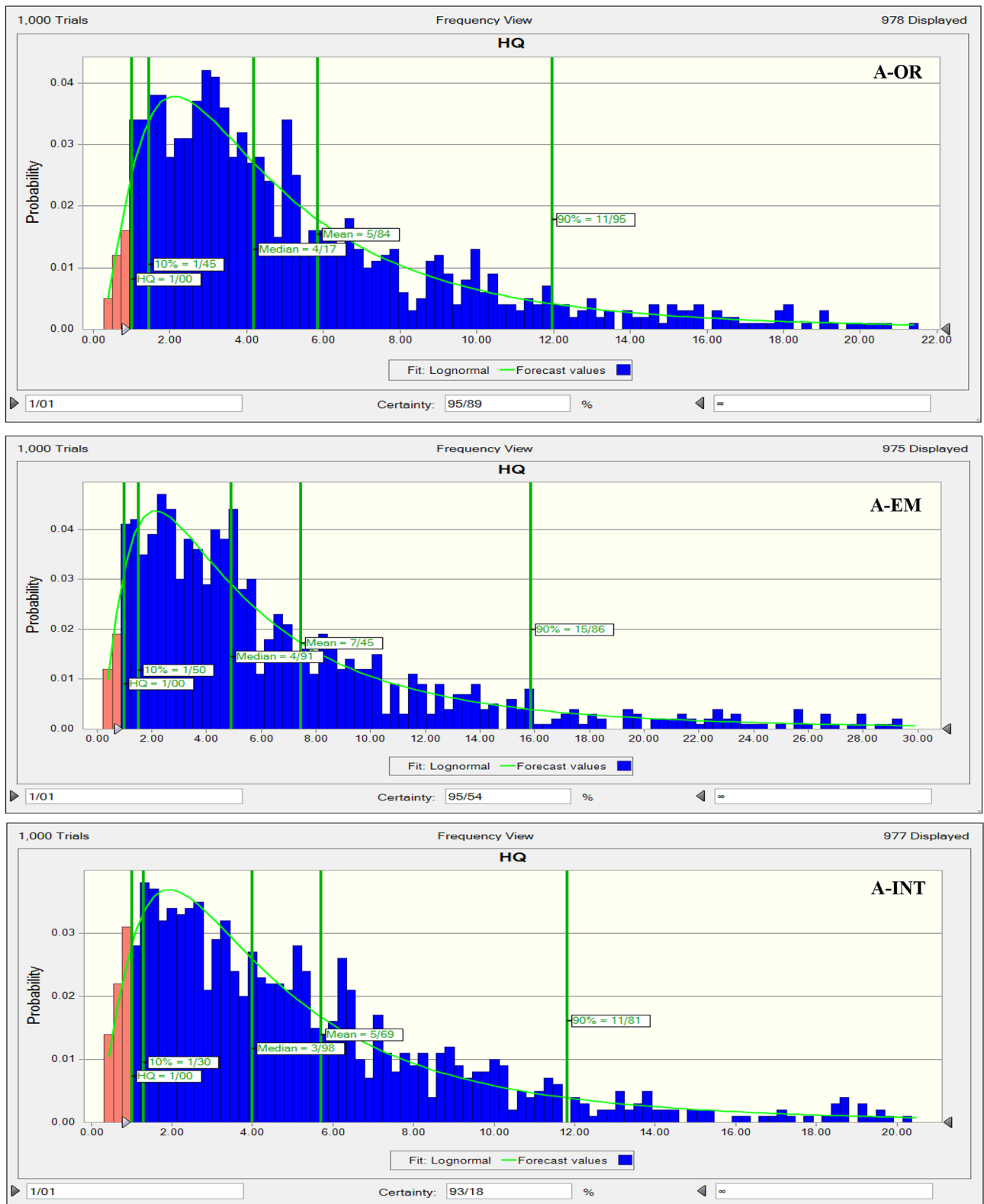


Fig. 3. Results of the Monte Carlo simulation related to PM health risks for workers in hospitals.

hospitals A and B (Fig. 4). The high PM concentration of particles with larger sizes may be due to the presence of more people in the INT ward during visiting hours and higher people’s movement in this ward. According to the results of a study, the mass concentration of PM in different shifts in the departments was almost similar, although the concentration was higher in the morning and evening shifts than at night. It has also been shown that the concentration of particles has increased significantly during public meeting hours and has reached

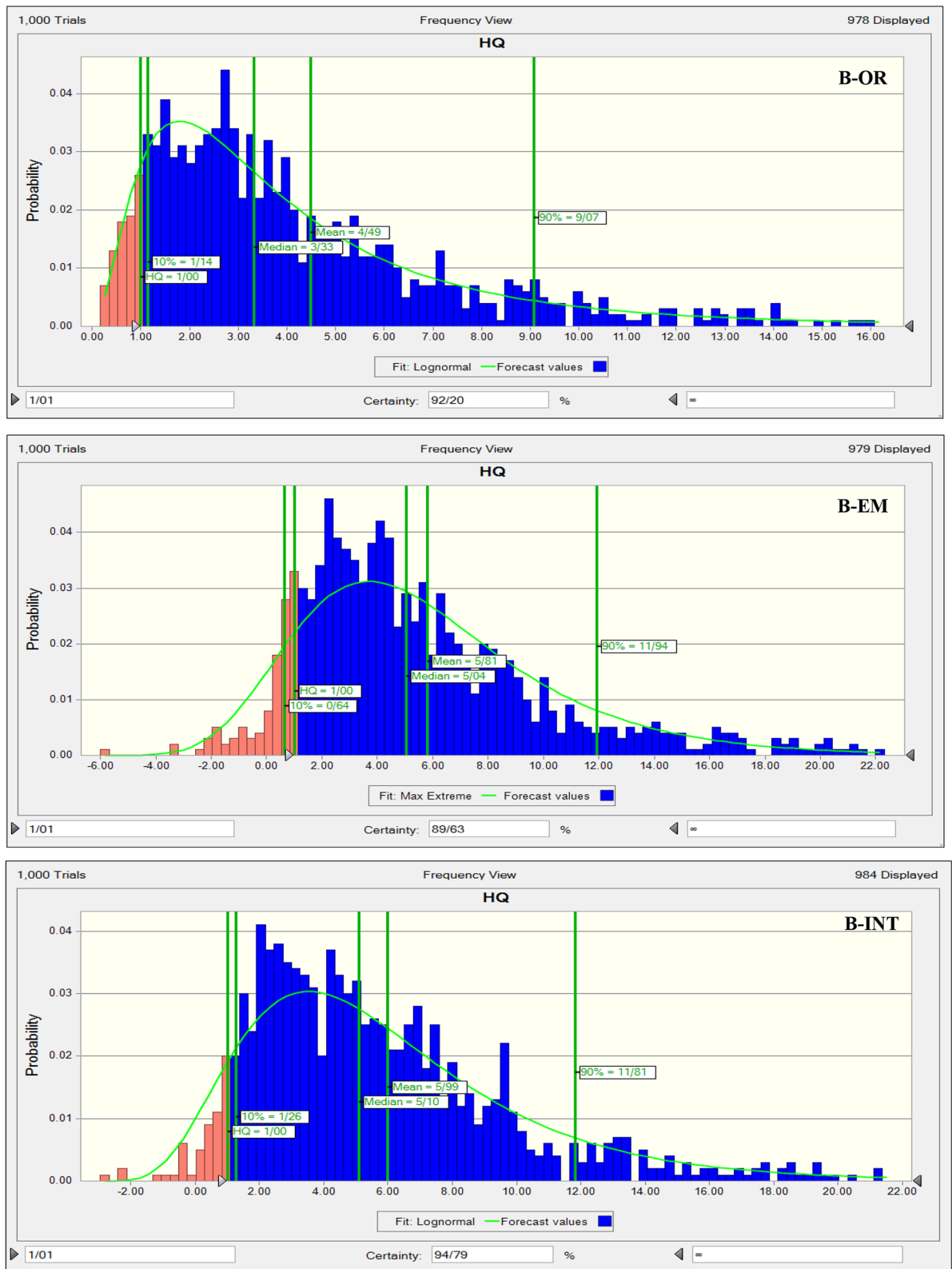


Fig. 3. (continued)

its highest level⁴⁵. Tang et al. investigated the contents of PMs and the effect of visitor numbers on the PM concentration in an intensive care unit (ICU) in a hospital in Taiwan. The results showed that the larger PM concentration (PM_{10}) increased more than the smaller particles with the increase in the visitors' number of this room⁵³.

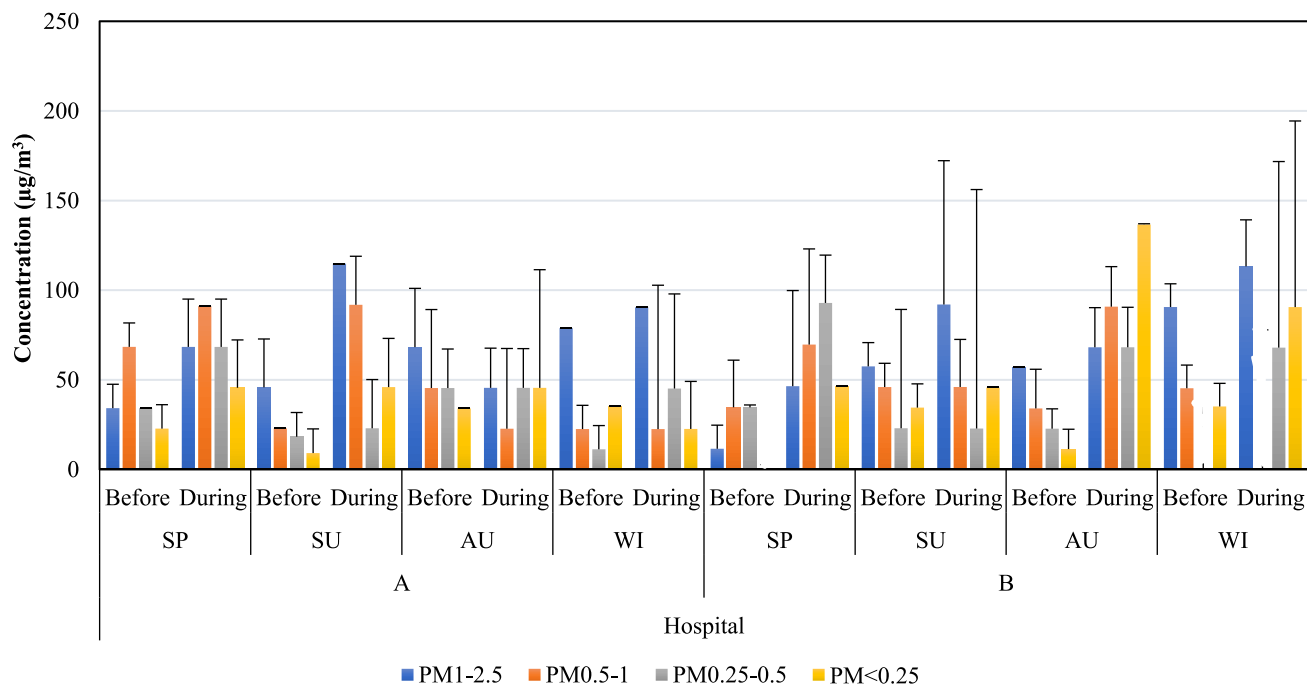


Fig. 4. The PM concentration of hospitals INT wards before/during visiting time in different seasons.

The HQ values for PM contents in visiting time are shown in Fig. 5. Therefore, to reduce the PMs health effects on healthcare workers and patients, special plans should be adopted to control the entry and exit of clients and visitors to hospitals. The average HQ values calculated during visiting time in the Monte Carlo model are higher than the HQ values calculated in the INT ward before visiting time. This designated high health risk can be caused by high concentration values of PM during the visiting time compared to before it. Enforcing control measures during visiting hours, including managing visitor movement, can reduce PM concentrations and thereby decrease the health risks linked to the release of these particles.

Bioaerosol concentration

The environmental parameters, bacterial, and fungal bioaerosols concentration in indoor air of different selected hospital wards during seasons were shown in Table 4. The average air temperature and humidity rate ranged from 22.2 to 26.4 °C and 37.9–65.9% during different seasons, respectively. The recommended temperature and humidity values related to American medical centers are determined as 20–23 °C and 60–30% respectively⁵⁴, which are lower than the values determined in this study. In both selected hospitals, the highest temperatures were shown in summer although the higher relative humidity in hospitals A and B was detected in summer and winter, respectively (Table 4). Additionally, statistical analyses revealed a positive correlation between the levels of fungi and humidity during the summer, autumn, and winter seasons (Table 5). The geographical location of Bushehr has a significant impact on the climate of the city including humidity, which is located close to the Persian Gulf Sea and is a coastal city. The weather conditions in Bushehr include long hot, and humid summer days. Accordingly, the highest concentration of bacteria and fungi in this study was observed during the summer season for two selected hospitals. The average bacterial and fungal concentrations ranged from 49–319 and 12–331 cfu/m³ in hospital A, and also that of in-hospital B were 83–160 and 209–42 cfu/m³, respectively. The highest bacterial and fungal concentration load among different wards was related to the EM of hospital A (767 cfu/m³) and B (776 cfu/m³) during summer, respectively. Therefore, the EM ward in hospitals can be one of the most polluted areas in terms of bioaerosols. Moreover, in most sampling cases, the OR had the lowest bioaerosols concentration compared to other wards. In general, the ventilation systems in the operating room should work better than in other wards because patients with acute conditions and also healthcare workers are present in this ward for a long time. Therefore, the presence of bioaerosols in the OR can be due to the inefficiency of the ventilation systems. The presence of bacteria in the operating room can be caused by microbial contamination spread from the skin, hair, and respiratory tracts of people in the OR. The amounts of bacteria in hospital B were higher than fungi during seasons in different wards. Although the bioaerosol contents in hospital A did not follow a constant trend, it was shown that the bacteria concentration was lower than that of fungi only in summer and winter. Affecting factors of bioaerosol contents in the hospital indoor air include the number of patients and visitors, temperature, time of day (hour) or year (month or season), relative humidity, construction, the relative concentration of particles or organisms, and the performance of air supply system⁵⁵. According to the WHO guidelines, the bacterial and fungal acceptable levels are 100 and 50 cfu/m³ in the hospitals' indoor air^{56–58}. Therefore, the majority of the determined bacteria and fungi values in this study were higher than the recommended standard, which indicates the high risk of bioaerosols in the hospitals' indoor air. In a study, Montazeri et al. investigated the amount of indoor air fungi and bacteria in the different wards of a hospital in



Fig. 5. Results of the Monte Carlo simulation concerning health risks associated with PM exposure for hospital workers during visiting time.

Yazd, Iran. The results of this study showed that the most bacterial contamination was related to the burns ward (294 cfu/m^3), operating (147 cfu/m^3), and emergency rooms (124 cfu/m^3), while the most fungal contamination was related to the skin ward (110 cfu/m^3)⁵⁹. In a study conducted in hospitals of Taiwan, the relationship has been investigated between various amounts of indoor air pollutants in different hospital wards, including bioaerosols, and ventilation systems. The results of this study showed that the amounts of bioaerosols in different wards did not differ significantly, but the concentration of bacteria ($396\text{--}1703 \text{ cfu/m}^3$) and fungi ($173\text{--}719 \text{ cfu/m}^3$) were higher than in the present study. It has also been observed that central air conditioning systems are more suitable for reducing bioaerosols in the indoor air of hospital wards³⁹.

Moon et al. investigated the bioaerosols amount (fungi, bacteria, and viruses) in the indoor air of residential houses in South Korea. The results of this study showed that the bacterial concentration ($280\text{--}673 \text{ cfu/m}^3$) was higher than that of fungi ($96\text{--}219 \text{ cfu/m}^3$) in indoor air. In this study, the highest concentration of bacteria and fungi was observed in summer and autumn, respectively. Also, the genus of different fungi has not been investigated and only fungal colonies have been counted⁶⁰.

Investigation effects of visiting time on the bioaerosol concentration

Another aim of the current study is to determine the amount of bioaerosols before and during the visiting hours of the INT ward, which is summarized in Fig. 6. The results showed that the bacterial concentration has increased in most of the sampling cases during visiting hours in different seasons compared to before it in both hospitals, while no such trend was observed for fungi. The increasing trend of three to four times the amount of bacteria during the visiting hour compared to before has been shown in various studies⁶¹. However, the abundance of fungal and bacterial measured values before and during the visiting hours was higher than the

Hospital	Ward	Season															
		SP				SU				AU				WI			
		TEMP. (°C)	HU. (%)	Bacterial Con. (±SD) (cfu/m ³)	Fungal Con. (±SD) (cfu/m ³)	TEMP. (°C)	HU. (%)	Bacterial Con. (±SD) (cfu/m ³)	Fungal Con. (±SD) (cfu/m ³)	TEMP. (°C)	HU. (%)	Bacterial Con. (±SD) (cfu/m ³)	Fungal Con. (±SD) (cfu/m ³)	TEMP. (°C)	HU. (%)	Bacterial Con. (±SD) (cfu/m ³)	Fungal Con. (±SD) (cfu/m ³)
A	OR	24.3	53.0	6 (±15)	2 (±28)	24.7	51.3	124 (±85)	94 (±83)	23.8	54.8	196 (±142)	108 (±8)	23.5	50.0	87 (±3)	216 (±215)
	EM	22.8	57.3	5 (±8)	1 (±18)	24.5	64.9	534 (±50)	776 (±1012)	24.2	61.6	428 (±155)	118 (±43)	24.9	49.9	140 (±73)	465 (±412)
	INT	24.0	55.4	136 (±3)	32 (±15)	23.8	65.9	300 (±195)	122 (±172)	23.2	58.1	124 (±50)	223 (±60)	23.5	37.9	64 (±35)	62 (±33)
	Mean	23.7	55.2	49 (±9)	12 (±20)	24.3	60.7	319 (±110)	331 (±422)	23.7	58.2	249 (±116)	150 (±37)	24.0	45.9	97 (±37)	248 (±220)
B	OR	25.0	52.2	228 (±28)	30 (±3)	24.3	52.0	216 (±115)	179 (±117)	23.2	57.3	131 (±10)	42 (±20)	22.6	56.6	83 (±8)	71 (±20)
	EM	24.6	51.6	152 (±15)	48 (±18)	26.4	43.4	767 (±45)	120 (±80)	27.1	41.2	500 (±307)	117 (±5)	23.6	49.0	300 (±5)	159 (±100)
	INT	25.1	47.0	691 (±58)	171 (±43)	24.4	54.0	281 (±13)	180 (±0)	22.2	53.7	332 (±100)	309 (±292)	23.7	49.5	244 (±20)	180 (±20)
	Mean	24.9	50.3	357 (±34)	83 (±21)	25.03	49.8	421 (±58)	160 (66)	24.2	50.7	313 (136)	156 (±106)	23.3	51.7	209 (±11)	137 (±47)

Table 4. Air temperature, relative humidity, and bioaerosols (bacterial and fungal) concentration in different wards of selected hospitals during seasons.

	Fungal	Bacterial	Humidity (%)	Temperature (°C)
Spring				
Fungal Col	1			
Bacterial Col	0.981	1		
Humidity (%)	-0.865	-0.863	1	
Temperature (°C)	0.661	0.603	-0.868	1
Summer				
Fungal Col	1			
Bacterial Col	0.319	1		
Humidity (%)	0.749	-0.138	1	
Temperature (°C)	-0.222	0.545	-0.776	1
Autumn				
Fungal Col	1			
Bacterial Col	0.058	1		
Humidity (%)	0.657	-0.442	1	
Temperature (°C)	-0.520	0.010	-0.733	1
Winter				
Fungal Col	1			
Bacterial Col	0.126	1		
Humidity (%)	0.217	0.897	1	
Temperature (°C)	0.144	0.177	-0.239	1

Table 5. Correlation coefficients between bioaerosol colonies and meteorological conditions during different seasons (Significant: *P* value < 0.05).

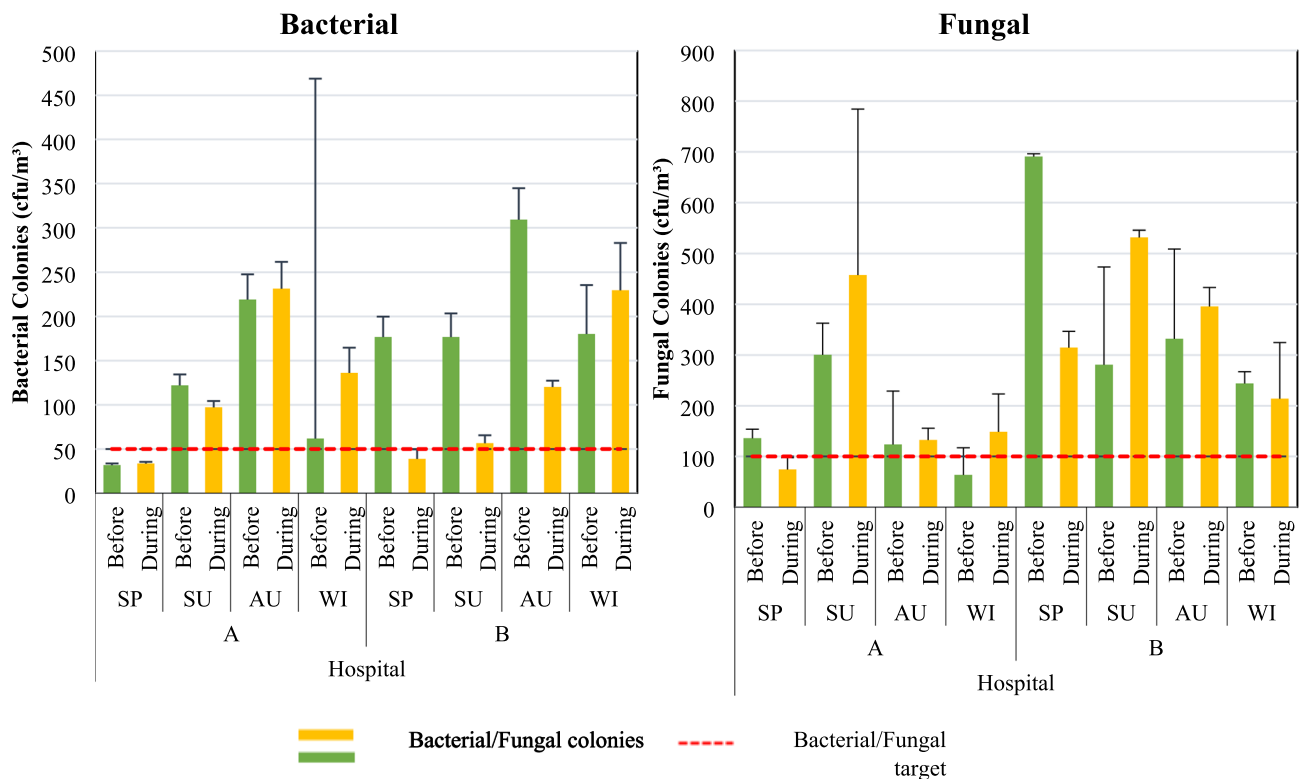


Fig. 6. Bacterial and fungal bioaerosols concentration (cfu/m³) before/during the visiting time in INT wards of selected hospitals during different seasons.

standard range suggested by WHO. Although the bacterial values in the spring season and the fungal values in the autumn season were higher than the standard limits before the visiting time in Hospital B. The difference in the changes of bacteria and fungi concentration before and during the visiting hours depends on various factors, including amounts of people moving, the number of patients in the ward, temperature conditions, and the humidity level of the wards. Mehrasabi et al. investigated the bacteria and fungi concentration in the indoor air of different Valiasr Hospital wards in Zanjan, Iran. It was observed that the number of bacteria in the infectious ward and the number of fungi in the infectious, ICU, otolaryngology, and general surgery wards were higher than the standards suggested by WHO, respectively⁶². Therefore, to reduce the amounts of bioaerosols to a safe and standard level in hospitals are needed proper filtration and ventilation systems.

Conclusion

In this study, the PM and bioaerosols concentration has been investigated in the indoor air of operating rooms, emergency, and internal wards in the hospitals of Bushehr coastal city for the first time. In addition, the effects of visiting times on the PM and bioaerosols concentration were evaluated in hospital wards. The highest PM amount was observed in the emergency room of the main Bushehr's hospital during the summer season. All the PM concentrations determined in this study were in the acceptable PM content based on the existing standards (ACGIH), although it can cause secondary infections and various diseases in patients and staff present in these departments during long-term contact. It was also observed that particles with larger sizes ($PM_{1-2.5}$) increased in INT wards during the visiting hours. However, the results of the Monte Carlo risk assessment showed a high health risk (HQ^1) for healthcare workers in hospitals. The visiting time had an increasing effect on the concentration of bacteria in most of the sampling cases. Based on the results of this study, the lowest and highest concentrations of bacteria and fungi have been observed in the OR in the spring season and the EM in the summer season, respectively. Therefore, continuous measurement of particles and bioaerosols is very important to determine the performance of ventilation systems in hospital wards. It is also essential for health centers to consider some instructions to control the indoor air quality in terms of different pollutants. Although today, the measurement of other pollutants is also necessary in the indoor air of hospitals, including gases and various chemical compounds.

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Received: 9 January 2025; Accepted: 26 May 2025

Published online: 01 July 2025

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Acknowledgements

The authors gratefully acknowledge the financial support for this work that was provided by the Iran University of Medical Sciences (Grant number: 1401-4-2-25078), and to the laboratory staff of the Systems Environmental Health and Energy Research Center, the Persian Gulf Biomedical Science Research Institute, for their cooperation.

Author contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [Mahbubeh Tangestani]. The first draft of the manuscript was written by [Mahbubeh Tangestani]. [Sina Dobaradaran], [Majid Kermani], and [Roshanak Rezaei Kalantary] commented on previous versions of the manuscript. All authors read and approved the final manuscript. The Project supervision were done by [Ahmad Jonidi Jafari].

Funding

The financial support for this work was provided by the Iran University of Medical Sciences (Grant number: 1401-4-2-25078).

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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