Assessment of Bioaerosol Pollution in Industrial and Urban Environments of Ouargla Region, Algeria

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Abstract:

Bioaerosol pollution in Industrial and Urban Environments can lead to the transmission of pathogenic microorganisms through inhalation. This study focused on measuring and analyzing bioaerosol concentrations in indoor and outdoor environments in urban and industrial areas and the factors affecting them. The study found that the concentration of airborne Bacteria indoors ranged from 29 to 1039 CFU/m^3, while outdoor concentrations ranged from 18 to 183 CFU/m^3. For Fungal concentration, indoor levels ranged from 3.7 to 83 CFU/m^3, whereas outdoor levels ranged from 1.8 to 106 CFU/m^3. Generally, the Bioaerosol concentrations were within safe limits, except in the Hospital and the National Drilling Company, where they exceeded the recommended guidelines of the National Institute for Occupational Safety and Health and the American Conference of Government Industrial Hygienists. Geographical location and climate were identified as significant, also human factors affecting Bioaerosol concentration. The study also emphasized the importance of further research on respiratory pathogens and the need for solutions to minimize Bioaerosol exposure.

Keywords: Bioaerosol, Bacteria, Factors, Fungi, Indoor, Outdoor.

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Abbreviations:

NIOSH: Institute National Occupational Safety and Health.

ACGIH: American Conference of Government Industrial Hygienists.

IRSST: Safety Research Institute Robert Sauve.

CFU/m^3: colony-forming unit per cubic meter.

R: Ratio

I: Indoor

O: Outdoor

PM2.5: Fine particulate matter.

S_I: Oil and gas processing laboratory National Company Sonatrach

So: Station yard National Company Sonatrach

E_I: Drinking water treatment plant at the life base National Drilling Company

E_O: Station yard National Drilling Company

H_I: The waiting room for the prevention and treatment of cancer patients

H_O Hospital Yard

L_I: Living room

$L_{O:}$ House Yard

F_I: Accessories Shop

F_O: Fuel Refueling Station

Introduction

Biological aerosols, also known as bioaerosols, are particles of microbial, animal, or plant origin suspended in the air [1, 2]. They can include bacteria, plants, fungi, animals, spores, protozoa, and plant pollen grains [3, 4]. Bioaerosols can be found in both indoor and outdoor environments [1], and their sizes range from 0.02 to 100 µm. Inhaling certain bioaerosols can affect human health and lead to asymptomatic or apparent infections, allergies, asthma, rhinitis, and toxic reactions [5–7].

The presence of bioaerosols in indoor and outdoor air is influenced by various factors. Activities such as traffic, construction, and gatherings of people in urban areas can significantly increase the concentration of Bacteria and Fungi in the outdoor environment [8–10]. The ratio values of indoor to outdoor (I/O Fungi or Bacteria) are commonly used to identify the emissions sources of bioaerosol. A Bacterial or Fungal ratio value of less than 1 indicates that outdoor air is the primary source, while a ratio value greater than 1 suggests internal sources. [11–13]

Environmental conditions such as relative humidity, temperature, and wind speed can also influence the quantity and quality of microorganisms in the air [5, 13–17]. Additionally, air conditioning systems in enclosed spaces, seasonal factors, weather conditions (sunny or rainy), and inadequate ventilation can impact the levels of bioaerosols. [18–22]

The quantity and quality of airborne microbes can vary depending on the time of day, year, and geographical location [23, 24]. Relative humidity, temperature, and seasonal factors are related to the concentration of microorganisms in indoor environments. [9, 20, 25]

Previous studies have shown that bioaerosol concentrations can exceed average levels in both indoor and outdoor environments, particularly in densely populated kindergartens [22]. Regional and seasonal differences, environmental conditions, and human activities have been found to affect bioaerosol concentrations and distributions [15, 26, 27]. For example, the number of active beds in hospitals with high concentrations of bacteria and fungi can impact bioaerosol concentrations. Seasonal variations have also been observed in outdoor airborne bacteria concentrations[27]. Additionally, the presence of airborne microbes in dust from desert areas can influence indoor and outdoor microbial air quality in hospitals. [28]

The objective of this study is to investigate the concentrations of bioaerosols (bacteria and fungi) and determine if their levels are within safe limits or pose potential health risks. The study aims to identify the sources of bioaerosols in both indoor and outdoor air in buildings and offices located in urban and industrial areas of the Ouargla Region in southeast Algeria. This research is crucial for environmental management and assessing potential health impacts.

Materials and Methods

Air Sampling Sites and Protocols

Description of Study Area: The city of Ouargla is located in the southeast of Algeria and is considered one of the largest desert and industrial cities. It covers an area of approximately 361,980 square kilometers. Ouargla is situated at latitude 31°58' north and longitude 5°20' east, with a population of around 140,000 people. The city extends over an area of 60 km2 in the Oued Mia region and ranges in elevation from 103 to 150 meters above sea level. It has a unique climate characterized by high temperatures, very dry air, monsoons, and sandstorms, particularly in the spring months of March and April. Ouargla is home to the largest sedimentary basin in Algeria, containing aquifers and oil-bearing layers. The region is highly active in oil exploration, with oil wells distributed within a radius of 100 km from the city. The environmental pollution caused by aerosols is expected to increase due to oil exploitation.[29]

Fig.1 and ***Table 1*** show the air sampling sites in Ouargla Region, Algeria.

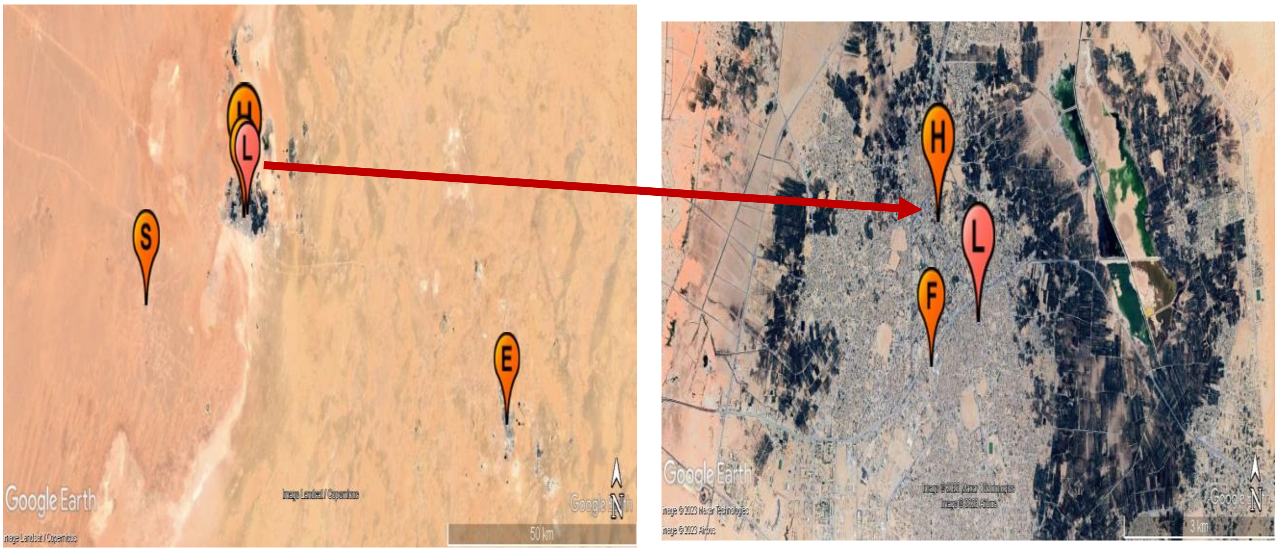

Fig.1: Sampling sites for measurement of Bioaerosol airborne in Industrial and Urban areas in Ouargla Region-Algeria

Two in Industrial Aera: National Company Sonatrach Houd Berkaoui (S) and National Drilling Company Hassi Messoude (E), and Tree in Urban Aera: Mohamed Boudiaf Hospital (H), House (L), Fuel station (F). The investigated locations and sites were characterized by distinct environmental contours (Fig. 1).

Table 1: Site, locations, and periods of Bioaerosol sampling

Area	Site	Location	Sample	Period
Industrial	**National Company Sonatrach (S)** Latitude: 31°50'34.37"N Longitude: 5° 3'32.41"E	Oil and gas processing laboratory Station yard	S_I S_O	Weekdays January 26, 2020
	National Drilling Company (E) Latitude: 31°42'4.56 "N Longitude: 6° 3'28.14"E	Drinking water treatment plant at the life base Station yard	E_I E_O	Weekdays February 12, 2020
urban	**Mohamed Boudiaf Hospital (H)** Latitude: 31°57'43.18"N	Waiting room for the prevention and treatment of cancer	H_I	Weekdays January 12,

	Longitude: 5°19'50.39"E	patients Hospital Yard	H_O	2021
	House (L) Latitude: 31°57'10.05"N Longitude: 5°20'21.43"E	Living room House Yard	L_I L_O	January 22, 2021
	Fuel station (F) Latitude: 31°56'55.19"N Longitude: 5°19'45.61"E	Accessories Shop Fuel Refueling Station	F_I F_O	Weekdays February 05, 2021

Impinging Method: It is a technique commonly used to study aerosols and involves the utilization of impingement devices, which are all-glass devices resembling nasal passages. These devices have a tube nozzle that allows air samples to enter and come into contact with a buffered liquid solution inside the tube. The impaction of the air samples in the liquid facilitates the analysis of aerosol particles. [30]

Impacting Method: It involves collecting airborne microorganisms by passing air through a porous medium, Different types of filter materials are available, including fiberglass filters, cellulose filters (membranes), and capillary pore filters (polycarbonate). These filters vary in porosity from 0.01 µm to 10 µm. [30, 31]

Preparation of Phosphate-Buffered Saline Solution and Cultivation Medium: Phosphate-buffered saline solution was prepared by suspending 8g of sodium chloride (Chem-Lab NV Co, Belgium), 0.2g of potassium chloride (SIGMA-ALDRICH Co, USA), 1.44g of sodium phosphate dibasic (SIGMA-ALDRICH Co, USA), and 0.24g of potassium phosphate monobasic (SIGMA-ALDRICH Co, USA) in distilled water. The pH of the buffer solution was adjusted to 7 by adding a few drops of hydrochloric acid (BIOCHEM Co, French) at a 1M concentration.

Plate Count Agar (PCA) and Potato Dextrose Agar (PDA) were used as cultivation media. For PCA, 23.5g of the medium (Scharlau Co, Spain) was suspended in 1L of distilled water and sterilized by autoclaving. Similarly, for PDA, 39g of the medium (CONDA pronadisa Co, Spain) was suspended in 1L of distilled water and sterilized. The solutions were sterilized by autoclaving at 121°C for 15 minutes.

Sampling Procedure: a bioaerosol sampling procedure was carried out in the Ouargla Region, During the winter season of January-February 2020/2021. Simultaneously, meteorological factors including temperature, relative humidity, and wind speed were monitored using a portable instrument (Pro'sKit MT-4616 LTD. Taiwan, R.O.C.) and data provided by the National Meteorological Authority. sampling was using a pump (Gilian Gilair 5, SESSIDYNE, USA) with a flow rate of 3 liters per minute (L/min). The air was passed through sterile mixed cellulose esters filters (MCE) with a diameter of 47 mm and pore size of 0.22 µm (Merck, Germany) for 1 Hour. The filters were then directly placed into Petri dishes, For the impacting method.

In the impingers method, the air was passed through a glass device has a tube nozzle that allows air to enter and come into contact with a 60ml buffered liquid solution inside the tube, Subsequently, the liquid was filtered using a vacuum pump (optic-ivymen-system), and the filters were collected and placed in Petri dishes.

Following the sampling process, the Petri dishes were immediately transferred to the laboratory in a cooler set at a temperature of 4°C. The dishes were incubated in a Memmert™ Standard Incubator (Fisher Scientific SAS., Ltd. French) at 37°C for a duration of 24 to 48 hours for bacteria and three to five days for fungi. After the incubation period, the results were analyzed using a colony counter (labolan M:570, Taiwan).

Variability of CFU Counts: To calculate the bacterial and fungal colony-forming units per cubic meter (CFU/m^3).

The following relationship was used: CFU/m^3 = (1000 × T) / (F × t). Here, 1000 is the conversion factor from liters to cubic meters, ***T*** represents the number of bacterial bioaerosols, ***F*** is the pump flow rate, and ***t*** is the duration of sampling in minutes.[15, 17, 30–33]

Results and discussion

Bioaerosol Concentrations Indoor Bacteria and fungi

The results obtained showed the concentrations of bioaerosols, which are aerosols of biological origin containing Bacteria and Fungi, in indoor and outdoor air at selected sites in our study, including industrial and urban areas of Ouargla Region during the winter season of **2020** and **2021**. The results are presented in ***Table*** **2** and shown in ***Fig*.2**.

Table.2. The concentration and Sources of Bacterial and Fungal Airborne in industrial and urban areas of the Ouargla Region.

Symbol	Concentration Bacterial (CFU/m3)				Concentration Fungal (CFU/m3)				Meteorological factors		
	Impaction	ratio	Impingin	ratio	Impaction	ratio	Impingin	ratio	T	RH	V

	B	I/O	B	I/O	F	I/O	F	I/O	(C°)	(%)	(m/s)
S_I	35	0.7	29	0.906	56	1.12	absence	/	14	32	6
S_O	50		32		50		1.8		18	17	7
E_I	37	1.321	750	25.86	5.6	/	absence	/	19	30	2
E_O	28		29		absence		absence		13	29	1.4
H_I	250	1.366	1039	6.927	83	2.964	3.7	/	17	44	3.4
H_O	183		150		28		absence		8	34	1.5
L_I	83	1.361	339	18.83	17	0.16	absence	/	8	56	2
L_O	61		18		106		22		7	44	1.5
F_I	89	1.141	206	3.075	17	3.036	absence	/	14	37	2.1
F_O	78		67		5.6		absence		14	45	1.7

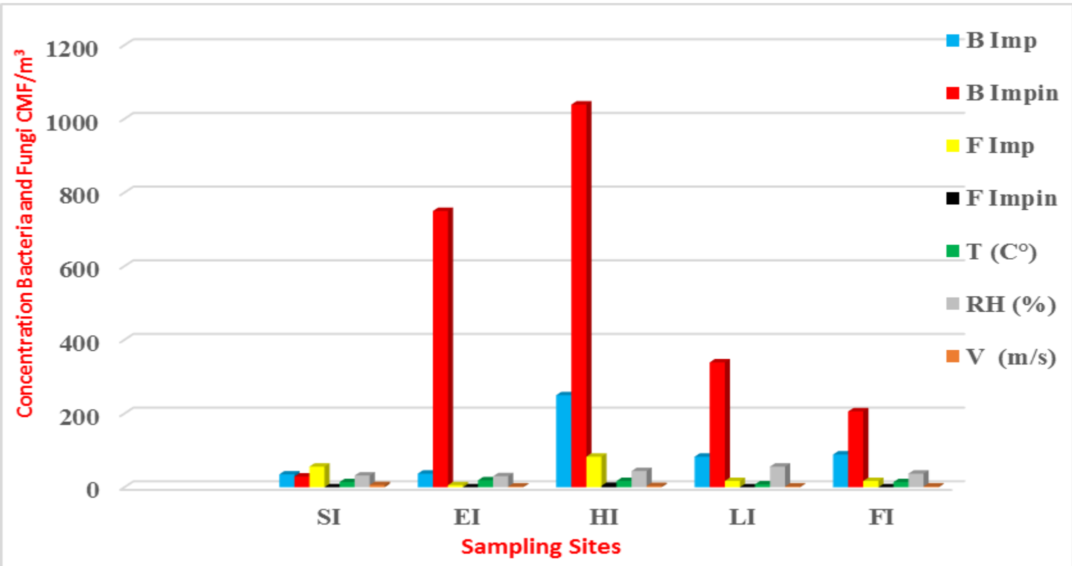

Fig2: Indoor Concentration of Bacteria and Fungi Airborne in Industrial and Urban Areas of Ouargla Region-Algeria

B: Bacteria, **F:** Fungi, Imp: Impaction method, **Impin:** Impinging method, **T:** Temperature, **RH:** Humidite Relative, **V:** Wind speed, S_I: Oil and gas processing laboratory National Company Sonatrach, E_I: Drinking water treatment plant at the life base National Drilling

Company, H_I: The waiting room for the prevention and treatment of cancer patients, L_I: Living room, F_I: Accessories Shop, F_O: Fuel Refueling Station

The indoor concentrations of Bacteria and Fungi at the study sites, using the Impingers method, ranged from 29 to 1039 CFU/m^3 for Bacteria. The Fungi were found in the indoor air of the H_I with a level of 3.7 CFU/m^3. its absence in other locations

When using the impaction method, Bacteria concentrations ranged from 35 to 250 CFU/m^3, while Fungi concentrations ranged from 5.6 to 83 CFU/m^3. Indoor Temperatures ranged from 8 to 19°C, Relative Humidity ranged from 30 to 56%, and Wind Speeds ranged from 2 to 3.5 m/s.

The highest indoor concentrations of Bacteria and Fungi were recorded in the H_I 1039 and 3.7 CFU/m^3 respectively, using the impaction method. And 250 and 83 CFU/m^3 using the sampling impacting method.

Bacteria concentrations were Low in the indoor air S_I 29 and 35 CFU/m^3 and the lowest concentration of Fungi was found at 5.6 CFU/m^3 in the E_I, with Both methods used, compared to other sampling sites

The outdoor air concentrations of Bacteria and Fungi at the study sites: are shown in *Fig.3*.

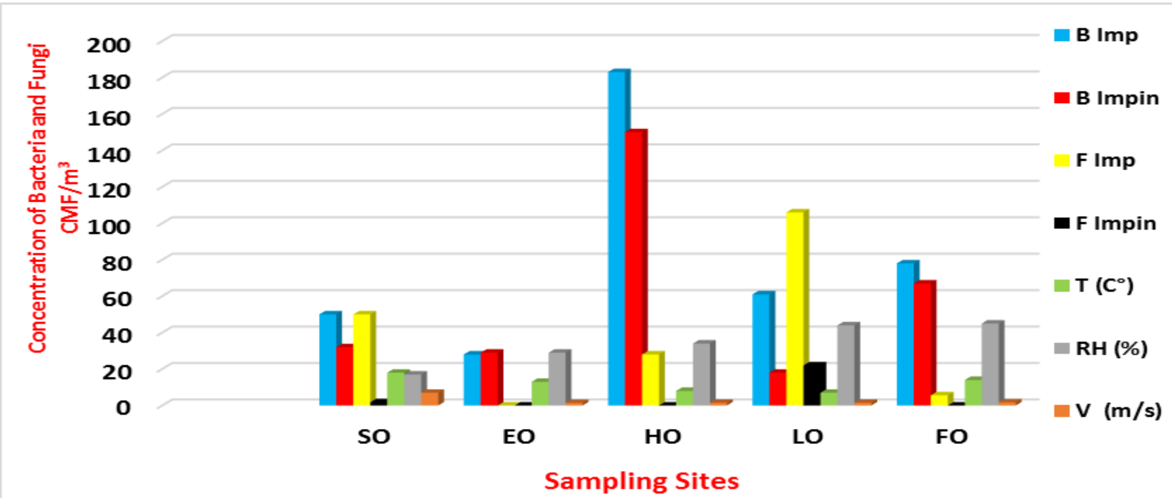

Fig3: Outdoor Concentration of Bacteria and Fungi Airborne in Industrial and Urban of Ouargla Region-Algeria

B: Bacteria, **F:** Fungi, Imp: Impaction method, **Impin:** Impinging method, **T:** Temperature, **RH:** Humidite Relative, **V:** Wind speed, **So:** Station yard National Company Sonatrach, E_O: Station yard National Drilling Company, H_O Hospital Yard, $L_{O:}$ House Yard, F_O: Fuel Refueling Station

The outdoor air concentrations of Bacteria and Fungi at the study sites, using the Impingers ranged from 18 to 150 CFU/m^3 for bacteria and 1.8 to 22 CFU/m^3 for Fungi. When using the impaction method, Bacteria concentrations ranged from 28 to 183 CFU/m3, while Fungi concentrations ranged from 5.6 to 106 CFU/m^3. Outdoor Temperatures ranged from 7 to 19°C, Relative Humidity ranged from 17 to 45%, and wind speeds ranged from 1.4 to 7 m/s. The highest outdoor concentrations of Bacteria were recorded in outdoor air the $\mathbf{H_o}$ 150 and 183 CFU/m^3 using both sampling methods. For fungi, the highest concentrations were observed in outdoor air the $\mathbf{L_o}$ 22 and 106 CFU/m^3. In general, Bacteria and Fungi. The lowest concentration of Fungi was found at 5.6 CFU/m3 in outdoor air the $\mathbf{F_o}$ using the impaction method, and 1.8 CFU/m^3 in outdoor $\mathbf{S_o}$ using the impinging method. Compared to other Sampling sites and not found in the outdoor air of the $\mathbf{E_o}$. The higher concentrations of Fungi and Bacteria in the open air can be attributed to other factors such as the presence of trees, animal husbandry and stables located in the nearby Houses, and the proximity of the sewage pumping station to the Hospital and the House. These factors can even impact indoor air quality. The reason for the low concentration of Fungi at the gas station is due to the movement of cars and trucks and the saturation of the air with dust particles.

It turns out that there is an inverse relationship between Temperature and relative Humidity in the internal and external environments. Geographical location and climatic conditions play crucial roles in determining the concentration of Bacteria and Fungi in outdoor and indoor air. The concentrations of Bacteria and Fungi indoors at the Hospital and the National Drilling Company exceeded the recommended levels established by NIOSH [14]. According to the recommendations of ACGIH and Rao [34, 35], the total count of Bacteria should not exceed 500 CFU/m^3, while the total count of Fungi should not exceed 200 CFU/m^3.

can vary depending on the season, location, and exposure to dust in desert environments play important roles in determining the concentration of bioaerosols in indoor and outdoor air, and can also affect the levels of indoor and outdoor aerosols. The concentration of airborne Bioaerosols is influenced by kinetic factors, chemical composition which contains organic and inorganic compounds, and meteorological factors. This was proven by previous studies on the difference in the concentration of bioaerosols according to the seasons of the year and meteorology [36–40]. Similar findings were reported in other studies, which have shown that the concentration of bioaerosols varies depending on the prevailing season and climatic conditions [41]. The concentration of bioaerosols is influenced by factors such as geography, climate, and exposure to meteorological factors. Factors like dust in desert environments can affect both indoor and outdoor aerosol levels [20, 42–45]. In Turkey, the highest level of airborne bacteria was found outdoors in autumn [46], while other research found that the highest levels of bacteria were recorded airborne in the summer[47].

Other studies have also shown that there are other factors affecting the concentration of bio-aerosols in indoor environments: density, population, and overcrowding in some public facilities: A difference was also found in the concentration of bio-aerosols in kindergartens in Rasht (Iran), due to the number of children, workers, and the ventilation process [22], as well as for nursing homes and school dormitories in Tehran (Iran) [48], and nursery and primary schools in France [49]. This is due to the density and number of children. It was also found that the concentration of aerosols within hospital care rooms in the USA was affected by activities such as bathroom cleaning, patient visit time, and disinfection material, resulting in a mist that could persist for more than 30 minutes after cleaning. The measured particle diameter was 0.3 µm [50–52]

In another study, the average observed indoor fungal concentration was 35.33 CFU/m^3, which is lower than the average fungal concentration ranging from 50 to 230 CFU/m^3 [53], but similar to average concentrations of 40 CFU/m^3 observed by [47]. The concentration of fungi can vary depending on the cleanliness or presence of mold in the apartment and other conditions. For example, in Gliwice, Upper Silesia, Poland, the maximum concentration in spring was 306 CFU/m^3, and the minimum concentration in winter was 49 CFU/m^3 [27]. In general, climatic conditions such as low temperatures, precipitation, and snowfall may contribute to lower levels of bacteria in the outdoor air [46, 50, 54, 55]. In Turkey, the highest level of airborne bacteria was found outdoors in autumn (Górny 2010), while other research found that the highest levels of bacteria were recorded airborne in the summer. [47]

It is important to note that there are currently no universally accepted standards or guidelines for bioaerosol concentrations and exposures. More research is needed to determine acceptable levels of contaminants. Some researchers have suggested that the concentration of airborne bacteria in outdoor air should not exceed 5,000 CFU/m^3 or the maximum regulatory levels for bacterial aerosols. The aerosol concentrations observed in our study were lower than the suggested standards of the IRSST, which recommended a limit of 1,000 CFU/m^3.[46]

Indoor and Outdoor Bacteria Sources

The ratio values of indoor to outdoor Bacteria (ratio I/O) are commonly used to identify the sources of aerosol emissions. If the ratio **I/O** is less than 1, it indicates that outdoor air is the source of airborne bacteria. On the other hand, if the ratio is greater than 1, it suggests that the indoor environment is responsible for the bacteria. [46, 56]

Air samples were collected under similar conditions at various study sites, and the results are presented shown in ***Fig.4.***

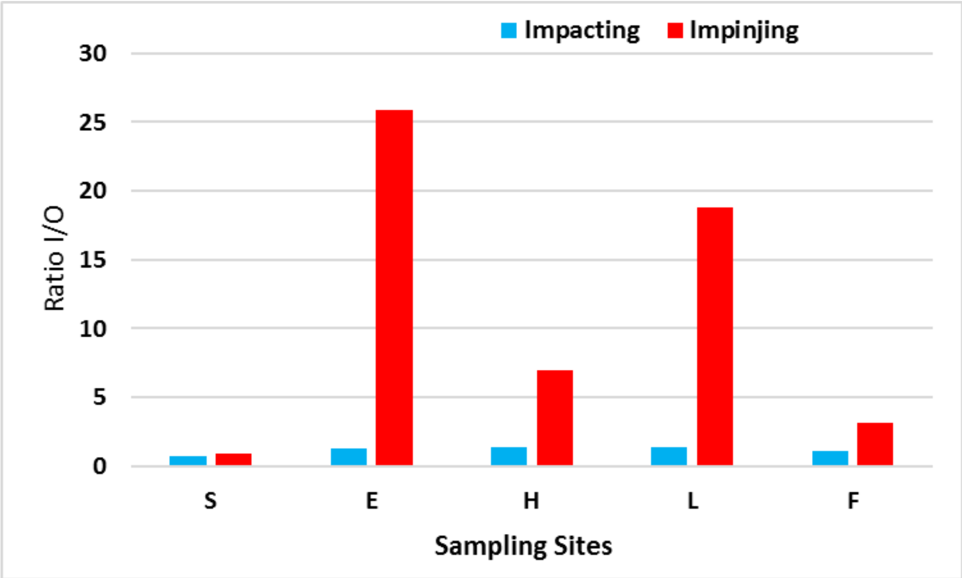

Fig4: Indoor/Outdoor Ratio for Identification of Bacterial Airborne Sources.

National Company Sonatrach Houd Berkaoui **(S)** and National Drilling Company Hassi Messoude **(E)**, Mohamed Boudiaf Hospital **(H)**, House **(L)**, Fuel station **(F)**, Indoor **(I)**, Outdoor **(O)**.

The ratio values of Bacteria ranged from 1.14 to 25.5 at these five sites. At the National Company Sonatrach site, the ratio values were less than 1 by 0.7, indicating that external air is the emission source of Bioaerosols (Bacteria). This implies that indoor air can become polluted with airborne bacteria from the outside through natural ventilation, as previous studies have found [23, 27, 57]. Similar findings have been observed in urban and rural primary schools in Lisbon, Portugal (ratio: 2.1) [50], a nursing home, and a school dormitory in Tehran, Iran (ratio: 1.44 and 1.77, respectively) [33]. These studies indicate that the main emission source of Bacterial aerosols in these environments is outdoor air. Positive correlations have also been found between outdoor bacterial aerosol concentrations in urban areas [13, 54, 58]. In Xi'an Province, northwest China, it has been observed that $PM_{2.5}$ concentrations affect Bioaerosols [10, 20, 59]. The presence of ventilation systems, air conditioning devices, and the use of disinfectants such as ClO_2 sprays can also impact the levels of Bacterial aerosols in indoor air, commonly seen in schools, kindergartens, Hospitals, and office buildings [43]. Furthermore, the high density of patients and crowding in Hospitals can contribute to an increase in the number of Bacteria in the indoor air, as seen during the coronavirus pandemic

Indoor and Outdoor Fungal Sources

According to the findings of this study, as presented shown in ***Fig.5***,

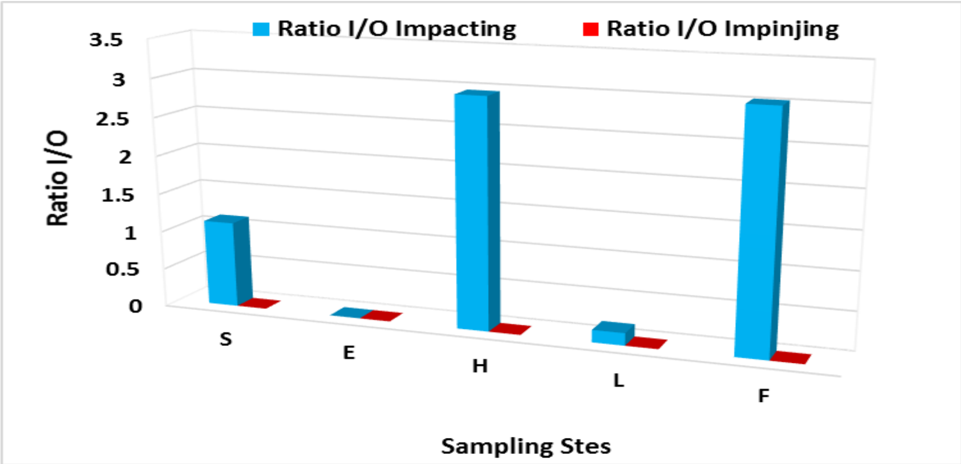

Fig5: Indoor/Outdoor Ratio for Identification of Fungal Airborne Sources.

National Company Sonatrach Houd Berkaoui **(S)** and National Drilling Company Hassi Messoude **(E)**, Mohamed Boudiaf Hospital **(H)**, House **(L)**, Fuel station **(F)**, Indoor **(I)**, Outdoor **(O)**.

the ratio values of indoor to outdoor Fungi (ratio I/O) ranged from **0.16** to **3.036**, indicating favorable conditions for Fungal growth indoors. The ratio I/O of airborne Fungi was greater than **1** (**ratio >** 1) in locations such as National Sonatrach, Hospital, and Fuel station, suggesting that airborne Fungi can act as contaminants. Fungal presence in indoor environments may occur through ventilation systems or pollutants originating from human activities and internal sources. Other studies conducted by researchers have also examined Fungal Bioaerosols and identified factors such as location and season, particularly spring and winter, as influential in fungal sources. These findings are consistent with the results obtained in Finnish homes, where Fungal concentrations were higher during spring and autumn and not during harsh climatic conditions like summer and winter [21, 22, 60]. The ratio values of airborne Fungi were less than **1** (**ratio <**1) in the House (ratio: **0.16**) and the drilling company, indicating that outdoor air served as the primary source of Fungal presence. This observation aligns with results from urban and rural primary schools in Lisbon, Portugal (ratio: **0.7**) [50]. Furthermore, in a study conducted in 16 different apartments, the highest ratio **I/O** Fungal of up to 200 were observed in apartments located in the northeastern United States, spanning from West Virginia to Maine [41]. These findings indicate that indoor-to-outdoor transmission of Fungal spores may occur through air leaks or ventilation systems. Additionally, Shelton and colleagues reported that maximum Fungal concentrations were observed in the summer and fall, while the lowest concentrations were observed in the spring. The findings of Lee et al. and Madsen et al. support the notion that Fungal aerosols can consist of viable, colony-forming particles as well as non-viable particles, both of which can have health effects in indoor environments. People are exposed to various

Fungal species, and pronounced dampness is associated with increased respiratory symptoms. [2, 47, 57, 61, 62]

Conclusion

In our study, we investigated the concentration of Bacterial and Fungal Bioaerosols in the Indoor and Outdoor air of Urban and Industrial Areas in Ouargla, Algeria, during the winter of 2020 and 2021. We found significant differences in bioaerosol concentrations, which were influenced by meteorological factors. The highest Bacterial concentrations were observed in the indoor Bioaerosols of the Hospital (1039 CFU/m^3), while the lowest concentration was found in the indoor air of the Sonatrach National Company (29.4 CFU/m^3). The highest concentration of Bioaerosols was recorded in the Hospital's outdoor yard, while the lowest concentration was observed in residential yards. Overall, it can be concluded that the air in Ouargla is relatively clean and of good quality, except for specific locations such as the Hospital and the National Drilling Company, where the concentration of Bioaerosols (Bacteria and Fungi) exceeded the recommended limits of 500 CFU/m^3 and 200 CFU/m^3, as suggested by the ACGIH and the World Health Organization. These areas can be considered as posing a risk in terms of air pollution, particularly for the health of patients and workers, as the high bioaerosol concentrations indicate poor indoor air quality, which provides favorable conditions for the growth of Bacteria and Fungi.

Furthermore, our study revealed a relationship between aerosol concentration and meteorological factors, including temperature, relative humidity, and wind speed. Additionally, the geographical location of the areas also played a significant role. The ratio values of Indoor and Outdoor bacteria (**ratio I/O**) were found to be greater than **1**, indicating that the main emission source of Bacteria and Fungi was human activity. To mitigate vital air pollution, it is crucial to implement regular ventilation and cleaning of air conditioning systems, especially in Hospitals and businesses with central air conditioners. Further research should be conducted to identify the causes of increased concentrations of bacteria and fungi, to improve the indoor air quality of various buildings and establishments.

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