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Assessment of microbial risks in the air of the Faculty of Engineering in Sabratha and its impact on health and safety

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Background: Indoor air quality (IAQ) in educational institutions significantly impacts public health and academic performance, yet bioaerosol dynamics in these environments remain understudied. This study evaluated airborne microbial loads and associated biological risks within the educational and administrative facilities of the Faculty of Engineering at Sabratha University.

Methodology: Utilizing the passive sedimentation (settle plate) method, indoor air samples were systematically collected across 30 distinct locations, including classrooms, lecture halls, specialized laboratories, administrative offices, and restrooms. To capture a comprehensive microbiological profile, samples were inoculated onto three distinct culture media: Nutrient Agar, Blood Agar, and MacConkey Agar. Isolated strains were subjected to phenotypic identification and standardized antibiotic susceptibility testing.

Results: Microbiological analysis revealed substantial bioaerosol contamination, with predominant growth observed on Nutrient Agar and Blood Agar. Phenotypic characterization confirmed the prevalence of *Staphylococcus* spp., *Enterococcus* spp., and *Escherichia coli*, alongside diverse airborne fungal assemblages. Conversely, MacConkey Agar exhibited zero growth across all sites, indicating a negligible baseline of robust, selective Gram-negative bacilli. Spatial distribution analysis demonstrated that restrooms and poorly ventilated administrative offices harbored the highest microbial densities. Furthermore, the density of *Staphylococcus* spp. correlated strongly with high anthropogenic occupancy in classrooms and lecture halls. Antibiotic susceptibility profiling indicated that the majority of bacterial isolates remained susceptible to frontline antimicrobial agents, displaying only marginal variations in resistance patterns.

Conclusion: The findings demonstrate that IAQ within the faculty is dynamically driven by structural ventilation limitations, localized human density, and sanitation protocols. To mitigate potential bioaerosol-mediated health risks, this study underscores the critical need for optimizing mechanical ventilation exchange rates, implementing stringent, scheduled disinfection regimens, and establishing continuous microbiological air-monitoring programs.

Keywords: Indoor air quality; Bioaerosols; Microbial risk assessment; Anthropogenic occupancy; Ventilation efficiency; Sabratha.

1. Introduction

Indoor air quality is one of the most important environmental factors affecting human health, comfort, and produtivity, given that individuals spend most of their time inside enclosed buildings, including educational institutions and universities

Microbial air contamination constitutes one of the principal components of indoor air pollution, encompassing bacteria, fungi, and fine biological particles capable of becoming airborne and affecting the health of building occupants Purnima et al.,2023 .

Airborne microorganisms constitute a major component of atmospheric bioaerosols, which consist of both living and non-living biological particles suspended in the air Shailaja et al .,2023

Bioaerosols encompass a diverse range of microscopic materials, including bacteria, fungal spores, pollen grains, microbial fragments, viruses, and other biological particles, occurring either as individual units or aggregated forms (Ruiz-Gil et al., 2020). Biological particles can contribute substantially to the total concentration of airborne particulate matter, accounting for approximately 10% of atmospheric aerosols in marine environments and up to 22–28% in inhabited and remote continental regions (Matthias-Maser et al., 2000; Jones & Harrison, 2004).

Classrooms, offices, and university laboratories are environments characterized by high occupancy density, which renders them susceptible to the accumulation of airborne microbial contaminants resulting from daily human activities such as breathing, speaking, and continuous movement. Limited ventilation combined with high numbers of occupants may further increase the concentration of microorganisms in indoor air, thereby raising the likelihood of exposure to health problems associated with the respiratory system, allergies, and certain infectious diseases Hitikk et al .,2023

Human activities and the operation of equipment within indoor environments are recognized as major contributors to the generation and dissemination of airborne microbial contamination Denina et al., 2012. Everyday activities such as speaking, coughing, sneezing, walking, and cleaning can release biological particles and microorganisms into the air, thereby increasing bioaerosol concentrations. In addition to human-related sources, various indoor materials and objects including food products, ornamental plants, flowerpots, household dust, textiles, carpets, wooden surfaces, and upholstered furniture can serve as reservoirs of microorganisms and fungal spores Abhilasha et al 2024. These materials may intermittently release microbial particles into the indoor atmosphere, contributing to the diversity and abundance of airborne microbial communities Sandhya et al.,2021

Recent studies indicate that airborne bacteria are influenced by a range of environmental factors, the most important of which include occupancy density, hygiene levels, temperature, relative humidity, and ventilation efficiency. Humans themselves represent the primary source of airborne bacteria within classrooms, through breathing, speaking, coughing, and body and clothing movement. Architectural design and ventilation systems likewise play a role in shaping the indoor microbial environment Steven et al.,2014.

Despite the growing importance of indoor air quality research, information regarding microbial contamination within Libyan university buildings remains limited, creating a knowledge gap concerning the level of microbial risk and the factors influencing it within such environments. In this context, the present study evaluates the level of microbial contamination in the indoor air of lecture halls and facilities at the Faculty of Engineering, Sabratha University, through the isolation and characterization of airborne bacterial organisms and the examination of the environmental factors influencing their spread, contributing to a scientific database that can be used to improve the educational environment and strengthen health and safety standards within the university institution.

Research Objectives

The overarching objective of this study was to evaluate airborne bacterial contamination in educational facilities at the Faculty of Engineering, Sabratha University, and to identify the environmental factors influencing microbial distribution within indoor environments. The study further aimed to characterize airborne bacterial isolates, assess their antimicrobial susceptibility patterns, and generate baseline data to support evidence-based indoor air quality management strategies in Libyan higher education institutions.

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Several studies have established a strong relationship between occupant presence and airborne microbial concentrations. Hospodsky et al. (2012) demonstrated that human activities, including movement, speaking, and other routine behaviors, contribute significantly to the release of bacteria-containing particles into indoor air. Similarly, Qian et al. (2012) reported that bacterial emission rates increase proportionally with occupancy density, indicating that the number of individuals present within a room directly influences microbial aerosol concentrations. Expanding upon these findings, Meadow et al. (2014) introduced the concept of the indoor microbial fingerprint, demonstrating that human occupants are the dominant source of indoor microbial communities and that each occupied space develops a unique microbial composition reflecting its users and patterns of occupancy.

Beyond human occupancy, building characteristics and environmental conditions play a fundamental role in shaping indoor microbial ecosystems. Kembel et al. (2012) revealed that architectural design, building materials, and ventilation strategies significantly influence microbial diversity and community structure within indoor environments. More recently, Madsen et al. (2023) reported that elevated relative humidity and inadequate ventilation create favorable conditions for microbial survival and proliferation, resulting in increased airborne microbial loads. In contrast, Li et al. (2023) demonstrated that enhanced ventilation and higher air exchange rates effectively reduce bacterial concentrations by diluting and removing airborne contaminants. These observations were further supported by Zhang et al. (2024), who found that classrooms with higher student densities consistently exhibited greater microbial contamination levels than less crowded environments, emphasizing the combined effects of occupancy and ventilation on indoor air quality.

The mechanisms underlying microbial contamination in educational buildings are closely linked to the continuous generation and resuspension of bioaerosols. Human activities such as walking, speaking, coughing, and movement of clothing can release microorganisms from the skin, respiratory tract, and surrounding surfaces into the air. Furthermore, dust accumulation, inadequate cleaning practices, and insufficient air circulation can facilitate the persistence and redistribution of microbial particles within indoor spaces. Consequently, microbial contamination levels are often higher in densely occupied environments with poor ventilation and limited air renewal.

Methodological approaches for assessing microbial air quality vary considerably among studies. Culture-based techniques remain widely used because of their simplicity, low cost, and ability to recover viable microorganisms. Among these methods, passive air sampling using settle plates has been extensively employed in educational and healthcare settings. Pasquarella et al. (2000) concluded that the settle-plate technique provides a practical and useful indicator of microbial air contamination, particularly for comparative environmental assessments, despite its limitations in accurately quantifying airborne microorganisms. More recent investigations conducted in educational institutions by Abu-Rub et al. (2021), Olusola-Makinde et al. (2022), and Muhammad (2025) similarly reported increased bacterial and fungal contamination during periods of active classroom

occupancy, highlighting the importance of occupancy density and ventilation efficiency as major determinants of microbial exposure.

Studies investigating the composition of indoor bacterial communities have consistently identified members of the genera Staphylococcus, Micrococcus, Bacillus, and other microorganisms associated with human skin and respiratory microbiota as dominant components of indoor air. The frequent detection of these organisms supports the view that humans serve as the principal source of airborne bacteria in educational environments. Although many of these microorganisms are considered part of the normal human microbiota, some species may act as opportunistic pathogens, particularly among susceptible individuals, thereby emphasizing the importance of maintaining adequate indoor environmental conditions.

3. Materials and Methods

3.1 Study Area

This study was conducted at the Faculty of Engineering, Sabratha University, Libya, during the Spring 2026 semester. Sampling locations included classrooms, lecture halls, teaching laboratories, administrative offices, restrooms, and the faculty library. The selected buildings differ in terms of ventilation characteristics, with some spaces relying primarily on natural ventilation through doors and windows, while others are equipped with air-conditioning systems. These variations provide an appropriate setting for investigating the influence of environmental conditions on airborne microbial contamination.

Sabratha is situated in a coastal region characterized by a Mediterranean climate with moderate to high relative humidity, conditions that may favor the survival, growth, and dispersion of airborne microorganisms, including bacteria and fungal spores.

3.2 Equipment and Materials

The equipment used in this study included a bacteriological incubator maintained at 37°C, an autoclave for sterilization, a light microscope equipped with an oil-immersion objective lens, a laboratory refrigerator for culture media storage, a digital analytical balance, and an electric heating device.

Consumable materials included sterile Petri dishes, glass microscope slides, sterile cotton swabs, disposable gloves, face masks, 70% ethanol for surface disinfection, and designated biohazard waste bags for safe disposal of contaminated materials.

3.3 Culture Media

Three microbiological culture media were employed for the isolation and cultivation of airborne bacteria:

- **Nutrient Agar (NA):** A general-purpose, non-selective medium used for the cultivation of a wide range of aerobic bacteria and estimation of total bacterial counts.
- **Blood Agar (BA):** An enriched medium supplemented with 5% sterile sheep blood, used for the isolation of fastidious organisms and assessment of hemolytic activity.
- **MacConkey Agar (MAC):** A selective and differential medium designed for the isolation of Gram-negative enteric bacteria and differentiation of lactose fermenters from non-fermenters.

All media were prepared according to the manufacturers' instructions and sterilized by autoclaving at 121°C for 15 minutes. After cooling to approximately 45–50°C, the media were aseptically poured into sterile Petri dishes. For Blood Agar, sterile sheep blood was added following cooling to prevent thermal damage to blood components. Prepared plates were allowed to solidify and were stored under refrigeration until use.

3.4 Air Sample Collection

Air samples were collected using the passive settle plate method (sedimentation technique), a widely used approach for assessing airborne microbial contamination in indoor environments. Sterile culture plates containing Nutrient Agar, Blood Agar, and MacConkey Agar were placed at a height of approximately 1–2 m above floor level to represent the human breathing zone.

Plates were exposed to the indoor environment for a predetermined sampling period and subsequently covered and transported to the laboratory for incubation. For each sampling point, information including location, sampling date, exposure time, and culture medium type was recorded.

Sampling was performed at 30 indoor locations distributed throughout the faculty buildings, including classrooms, lecture theatres, teaching laboratories, administrative and academic offices, restrooms, and the library. Three culture media were used at each sampling location.

The concentration of airborne bacteria was estimated using Omeliansky's equation:

$$\mathbf{N = (5a \times 10^4) / (b \times t)}$$

where:

- **N** = bacterial concentration in air (CFU/m^3)
- **a** = number of colonies counted on the plate
- **b** = surface area of the Petri dish (cm^2)
- **t** = exposure time (minutes)

3.5 Incubation and Bacterial Identification

Following sampling, culture plates were incubated in an inverted position at 37°C for 24–48 hours to prevent condensation from accumulating on the agar surface. After incubation, colony-forming units (CFUs) were counted and colony morphology was recorded, including size, shape, elevation, margin characteristics, pigmentation, and hemolytic activity where applicable.

Representative colonies were sub-cultured to obtain pure isolates for further identification. Preliminary bacterial characterization was performed using Gram staining following standard microbiological procedures involving crystal violet, iodine solution, alcohol decolorization, and safranin counterstaining. Microscopic examination was subsequently conducted to determine cellular morphology, Gram reaction, and cellular arrangement and biochemical tests, including catalase and coagulase reactions, were performed to identify the bacterial isolates at the genus level.

3.6 Antibiotic Susceptibility Testing

Antimicrobial susceptibility testing was carried out using the Kirby–Bauer disk diffusion method on Mueller–Hinton Agar following the guidelines of the Clinical and Laboratory Standards Institute (CLSI).

Pure bacterial cultures were suspended in sterile saline solution and adjusted to match the turbidity of a 0.5 McFarland standard. The bacterial suspension was evenly spread across the surface of Mueller–Hinton Agar plates using sterile swabs to obtain a uniform bacterial lawn.

The following antibiotic discs were tested:

- Ciprofloxacin (CIP)
- Ceftriaxone (CRO)
- Gentamicin (CN)
- Tetracycline (TE)
- Chloramphenicol (C)

- Amoxicillin (AML)

The inoculated plates were incubated at 37°C for 18–24 hours. Following incubation, inhibition zone diameters were measured in millimeters and interpreted according to CLSI breakpoint criteria. Isolates were classified as Susceptible (S), Intermediate (I), or Resistant (R) based on established interpretive standards.

4. Results and Discussion

4.1 Characterization of the Study Area

A total of 30 indoor locations within the Faculty of Sabrhta Engineering, Sabratha University, were surveyed and assessed. The investigated sites included classrooms, lecture halls, laboratories, administrative offices, restrooms, and the library. These locations differed in terms of building characteristics, occupancy density, ventilation type, and frequency of use. Some areas relied mainly on natural ventilation through windows and doors, whereas others depended on air-conditioning systems. Such variations provided an opportunity to evaluate the influence of environmental and operational factors on airborne microbial contamination.

The investigated sites were selected to represent the major functional spaces within the Faculty of Engineering, including teaching, research, and administrative areas. Collectively, these environments reflect the diversity of indoor conditions routinely encountered by building occupants and provide a representative framework for evaluating spatial variations in airborne bacterial contamination under normal occupancy and building operation conditions.

4.2 Microbial Growth on Different Culture Media

Microbial growth was observed on both Nutrient Agar and Blood Agar media, while no growth was detected on MacConkey Agar throughout the sampling period.

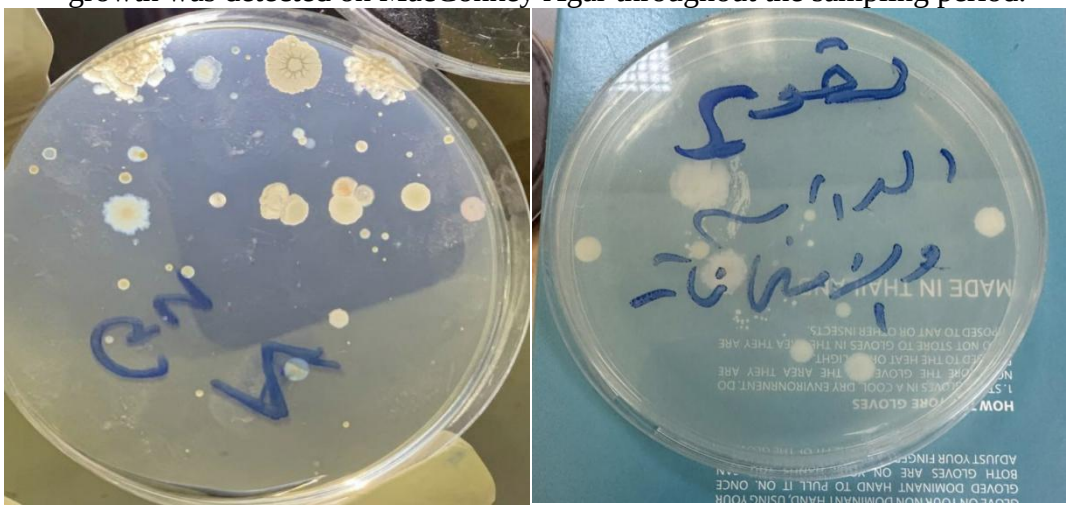

Figure 4.1 shows the presence of various bacterial and fungal forms on Nutrient agar

Nutrient Agar supported the growth of several bacterial genera, including *Staphylococcus spp.*, *Escherichia coli*, and *Enterococcus spp.* in addition to various fungal colonies as shown figures 4.1. The frequent occurrence of *Staphylococcus spp.* is consistent with its role as a common component of human skin and respiratory microbiota and suggests that human occupancy was a major contributor to airborne bacterial contamination. Similar findings have been reported in educational buildings where human activity significantly increased airborne bacterial concentrations.

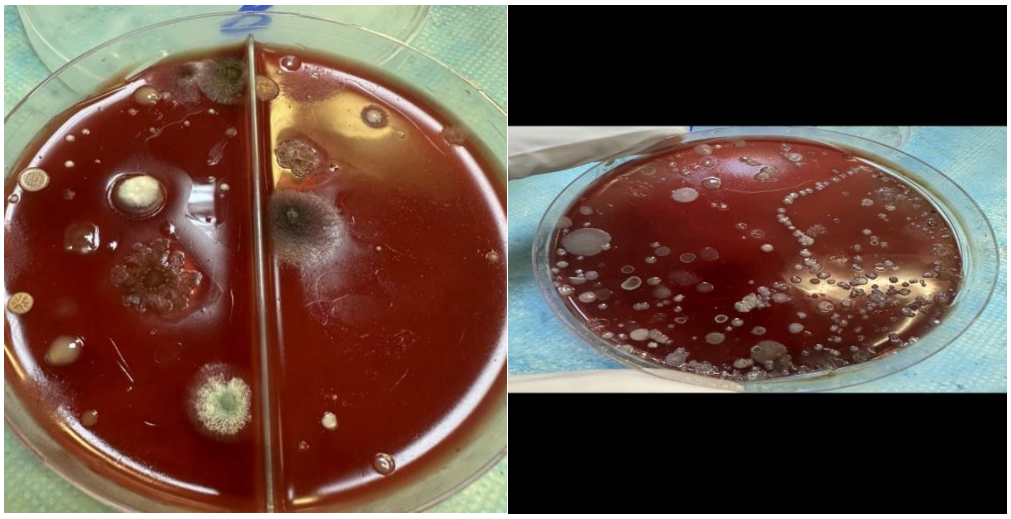

Figure 4.2 shows the presence of various bacterial and fungal forms on blood agar.

Blood Agar also supported the growth of *Staphylococcus spp., E. coli,* and several fungal isolates. The recovery of bacterial colonies on this enriched medium indicates as shown at figures 4.2 the presence of microorganisms capable of surviving and dispersing under indoor environmental conditions. The occurrence of hemolytic colonies may further suggest the presence of potentially opportunistic bacterial strains originating from human sources.

The detection of *E. coli* and *Enterococcus spp.* in some indoor locations may indicate indirect contamination originating from human activities, dust particles, footwear, or proximity to sanitary facilities. Although these organisms are primarily associated with the intestinal microbiota, their occasional detection in indoor air has been documented in educational and public buildings, particularly where ventilation is inadequate.

No bacterial growth was observed on MacConkey Agar. This finding may indicate either the absence or very low concentration of viable airborne Gram-negative bacteria. In addition, Gram-negative bacteria generally exhibit lower resistance to desiccation and environmental stress compared with Gram-positive bacteria, reducing their ability to remain airborne for extended periods. Similar observations have been reported in previous studies investigating microbial contamination in indoor environments.

4.3 Comparison of Microbial Contamination Among Different Locations

Differences in microbial contamination were observed among investigated locations. Classrooms and lecture halls exhibited frequent isolation of *Staphylococcus spp.,* particularly in areas characterized by high student occupancy and continuous movement. These findings support previous studies demonstrating a positive relationship between occupancy density and airborne bacterial concentrations.

The lecture theatre, ENV1, ENV2, R16, and C2 classrooms showed recurrent isolation of *Staphylococcus spp.*, suggesting that human presence was the primary source of contamination. Continuous movement, speaking, and respiratory emissions are known to contribute significantly to the release of bioaerosols into indoor air.

Table 4.1 show bacteria contamination among diffèrent location

Hall No.	Hall/Location Name	Medium Showing Growth	No. of Windows	Isolated Microorganisms
1	ENV2	Nutrient Agar	3	Staphylococcus, fungi
2	ENV1	Nutrient Agar	3	Staphylococcus, airborne fungi
3	R18	Blood Agar	2	Fungi, E. coli
4	Hall 2 – Petroleum & Chemical Eng.	Blood Agar	3	Staphylococcus, fungi
5	Drawing Studio 3	Blood Agar / Nutrient Agar	5	E. coli
6	R16	Blood Agar	3	Staphylococcus, fungi
7	C2	Nutrient Agar	2	Staphylococcus
8	C5	Blood Agar	2	E. coli
9	R20	Blood Agar	2	E. coli
10	Hall 67	Blood Agar	4	E. coli, fungi
11	Lecture Theatre	Blood Agar	10	Staphylococcus

Table 4.1 presents the eleven locations among the thirty surveyed sites that exhibited detectable microbial growth on at least one culture medium; the remaining nineteen sites showed no recoverable colonies under the sampling conditions used and are therefore not listed individually.

In contrast, *E. coli* was isolated from several locations as showen in figure 4.1, including Drawing Studio 3, R18, C5, R20, and Hall 67. The occurrence of these bacteria may be associated with insufficient ventilation and the accumulation of dust particles carrying microorganisms from external or indoor sources. Such findings emphasize the importance of adequate air exchange in reducing microbial accumulation within enclosed spaces.

Administrative offices and restrooms generally demonstrated higher contamination levels than well-ventilated classrooms. This pattern may be attributed to limited air circulation, prolonged occupancy periods, and reduced air renewal rates. Similar trends have been reported by previous investigations examining indoor microbial air quality in educational institutions.

Overall, the results demonstrate that occupancy density, ventilation efficiency, and building usage patterns are among the principal factors influencing microbial contamination levels within university buildings.

4.4 Estimation of Airborne Bacterial Concentrations

Airborne bacterial concentrations were estimated using Omeliansky's equation based on passive settle-plate sampling. Standard Petri dishes with a diameter of 9 cm (surface area = 63.6 cm^2) were exposed to indoor air for 20 minutes.

For example, in Hall 67, where 42 colonies were counted, the bacterial concentration was calculated as follows:

$N = (5 \times 42 \times 10^4) / (63.6 \times 20) = 1{,}651$ CFU/m³

Restroom facilities exhibited the highest bacterial concentrations among all investigated locations, exceeding internationally accepted reference values for indoor microbial contamination.

The results further demonstrated a positive correlation between student occupancy and the level of microbial contamination, with classrooms accommodating higher numbers of students exhibiting the greatest microbial colony counts. This relationship is likely attributable to the increased generation and resuspension of microorganism-laden particles associated with human activities, including movement, speaking, sneezing, and coughing. These findings are consistent with numerous recent studies reporting that high occupant density, together with inadequate ventilation, significantly increases airborne microbial loads in educational buildings (Madureira et al., 2020; Dancer, 2020).

Table 4.2 calculations yielded bacterial concentrations

Sampling location	**Bacterial concentration (CFU/m³)**
Student Affairs Office	1,850
Study and Examination Office	1,400
Examination Photocopy Office	1,450
Dean's Office	800
Hall 67	1,651
Classroom R23	1,240
Classroom R18	960
Drawing Studio 1	480
Drawing Studio 2	535
Drawing Studio 3	548

Restroom facilities exhibited the highest bacterial concentrations among all investigated locations, exceeding internationally accepted reference values for indoor microbial contamination.

Consequently, these findings represent an environmental warning signal requiring corrective interventions aimed at improving indoor air quality.

Airborne bacterial concentrations (CFU/m³) were estimated using the Omeliansky equation, an empirical conversion formula commonly applied to passive settle-plate sampling. Although this method does not directly measure a known air volume and therefore provides an approximate estimate of airborne microbial concentrations, it remains widely used for comparative assessments of indoor microbial air quality because of its simplicity, low cost, and suitability for environmental monitoring (Pasquarella et al., 2000; ISO 14698-1:2003).

Exposure of nutrient agar and fungal culture plates to classroom air for 30 min resulted in the growth of a diverse microbial community. Bacterial colonies exhibited considerable variation in colony morphology, ranging from smooth circular colonies to large rough wrinkled colonies. In addition, several filamentous fungal colonies with cottony or velvety aerial mycelia were observed. These findings indicate the presence of airborne microbial contamination within the classroom environment, most likely originating from human occupancy, dust resuspension, and ventilation-associated air movement.

Table 4.3. Morphological characteristics of the isolated microbial colonies.

Isolate Code	Colony Color	Colony Shape	Margin	Elevation	Texture	Gram Stain / Microscopic Features	Presumptive Identification
A1	Creamy white	Circular	Entire	Convex	Smooth	Gram-positive cocci in clusters	*Staphylococcus* spp.
A2	Pale yellow	Circular	Entire	Convex	Smooth	Gram-positive cocci in tetrads	*Micrococcus* spp.
A3	White	Irregular	Undulate	Raised	Rough, wrinkled	Gram-positive spore-forming rods	*Bacillus* spp.
F1	Grayish-green	Circular, filamentous	Filamentous	Raised	Cottony	Septate hyphae with conidial heads	*Aspergillus* spp.
F2	Bluish-green	Circular	Filamentous	Raised	Velvety	Septate hyphae with brush-like conidiophores	*Penicillium* spp.

Table 4.4. Total bacterial and fungal colonies recovered after passive air sampling (30-min exposure).

Classroom	Number of Students	Exposure Time	Bacterial Colonies	Fungal Colonies	Total Colonies
C1	25	30 min	18	4	22
C2	40	30 min	31	7	38
C3	55	30 min	42	11	53

Discussion

The passive air sampling method demonstrated that classroom air contained a diverse assemblage of airborne microorganisms, with bacterial colonies substantially outnumbering fungal colonies in all sampled classrooms. Morphological characterization combined with Gram-staining analysis allowed the presumptive identification of the dominant bacterial isolates as *Staphylococcus*, *Micrococcus*, and *Bacillus*, whereas the predominant fungal isolates exhibited morphological characteristics consistent with *Aspergillus* and *Penicillium*. Because identification was based solely on phenotypic characteristics, these taxonomic assignments should be regarded as presumptive pending biochemical or molecular confirmation.

The predominance of *Staphylococcus* spp. and *Micrococcus* spp. is consistent with their well-established role as dominant constituents of indoor airborne bacterial communities. These genera are common members of the normal human skin and upper respiratory microbiota and are continuously released into indoor air through normal human

activities, including movement, talking, coughing, and sneezing. Consequently, they frequently represent the major bacterial component of indoor bioaerosols in educational buildings, hospitals, and office environments (Awada et al., 2022).

Large wrinkled colonies presumptively identified as *Bacillus* spp. were also recovered from classroom air. Members of this genus produce highly resistant endospores that readily survive environmental stresses and become airborne following disturbance of soil and settled dust. Their presence therefore reflects the contribution of outdoor particles transported indoors through ventilation systems, open windows, footwear, and human movement. Similar findings have been consistently reported in studies investigating indoor airborne microbial contamination in educational facilities (Frankel et al., 2023).

Among the fungal isolates, colonies morphologically consistent with *Aspergillus* spp. and *Penicillium* spp. predominated. These filamentous fungi are widely recognized as the most abundant airborne fungal genera in indoor environments because of their prolific production of lightweight conidia that disperse efficiently through air currents. Their abundance generally increases under conditions of inadequate ventilation, elevated humidity, and dust accumulation. Several species within these genera are also recognized as important allergens and opportunistic pathogens, making their occurrence an important indicator of indoor environmental quality (Prussin & Marr, 2021).

The quantitative analysis revealed a progressive increase in microbial colony counts with increasing classroom occupancy. Total colony counts increased from 22 colonies in Classroom C1 (25 students) to 53 colonies in Classroom C3 (55 students), demonstrating a clear positive relationship between occupancy density and airborne microbial contamination. This trend is consistent with the concept that humans are the primary source of indoor bioaerosols, contributing microorganisms directly through shedding of skin particles and respiratory emissions while simultaneously resuspending settled dust through physical activity. Numerous investigations have demonstrated that high occupant density, particularly when combined with inadequate ventilation, substantially elevates airborne microbial concentrations in educational buildings (Madureira et al., 2020; Dancer, 2020).

Overall, the microbial composition observed in this study closely resembles that reported for indoor educational environments worldwide, where Gram-positive cocci originating from human occupants and spore-forming bacteria and filamentous fungi originating from environmental reservoirs constitute the dominant airborne microbiota. These findings emphasize the importance of maintaining effective ventilation, controlling classroom occupancy, implementing regular cleaning practices to minimize dust accumulation, and conducting routine microbiological monitoring to improve indoor air quality and reduce potential health risks associated with airborne microbial exposure.

4.5 Implications of Elevated Airborne Bacterial Concentrations

Elevated airborne bacterial concentrations may have important implications for both public health and building performance

4.5.1 Health Implications

High microbial concentrations increase the probability of exposure to infectious respiratory droplets and bioaerosols, thereby facilitating the transmission of respiratory pathogens. Elevated microbial loads may also contribute to allergic sensitization, chronic respiratory irritation, and exacerbation of asthma among susceptible individuals. Furthermore, prolonged exposure to poorly ventilated indoor environments containing elevated microbial concentrations has been associated with symptoms characteristic of Sick

Building Syndrome (SBS), including headache, fatigue, mucosal irritation, dry eyes, and reduced overall well-being.

4.5.2 Impact on Academic Performance

Poor indoor air quality resulting from elevated microbial contamination is frequently associated with inadequate ventilation and increased indoor carbon dioxide (CO_2) concentrations. These conditions have been linked to reduced cognitive performance, impaired concentration, decreased learning efficiency, increased fatigue, and higher rates of absenteeism among students and staff.

4.5.3 Factors Contributing to Elevated Microbial Loads

The elevated bacterial concentrations observed in this study are likely attributable to two principal factors. First, overcrowding substantially increases microbial emissions through continuous shedding of skin particles and respiratory droplets from occupants. Second, inadequate ventilation, reflected by low air-change rates (ACH), limits the removal and dilution of airborne microorganisms, allowing microbial particles to accumulate within indoor spaces. Administrative offices receiving frequent student traffic also exhibited elevated bacterial concentrations, most likely due to continuous occupancy and repeated human movement throughout the working day.

4.6 Antibiotic Susceptibility of Bacterial Isolates

The antibiotic susceptibility profiles of the selected bacterial isolates indicated generally high sensitivity to Ciprofloxacin, Gentamicin, and Ceftriaxone. However, variations in susceptibility were observed for Amoxicillin and Tetracycline among certain isolates.

The observed susceptibility patterns suggest that the isolated bacteria have not yet developed widespread antimicrobial resistance. Nevertheless, the detection of environmental bacterial isolates within educational buildings highlights the importance of continuous surveillance programs to monitor potential changes in resistance patterns over time.

Regular monitoring of antimicrobial susceptibility is particularly important given the increasing global concern regarding the environmental dissemination of antibiotic-resistant microorganisms and their potential impact on public health.

5. Conclusions

This study evaluated airborne bacterial contamination within selected indoor environments at the Faculty of Engineering, Sabratha University. Air samples collected from classrooms, lecture halls, laboratories, administrative offices, restrooms, and the library revealed the presence of bacterial and fungal contamination with varying distribution among locations.

The most frequently isolated bacterial genera included *Staphylococcus spp., Escherichia coli*, and *Enterococcus spp.*. Microbial contamination levels were influenced by several environmental and operational factors, particularly occupancy density, ventilation efficiency, hygiene conditions, and intensity of daily activities.

Nutrient Agar and Blood Agar proved effective for the isolation and cultivation of airborne microorganisms, whereas MacConkey Agar showed no detectable bacterial growth during the study period. The predominance of *Staphylococcus spp.* highlights the important role of human occupants as a primary source of indoor airborne bacteria.

The antibiotic susceptibility results demonstrated that most isolates remained susceptible to commonly used antimicrobial agents, although continued monitoring remains necessary to detect any emerging resistance trends.

Overall, the findings emphasize the importance of maintaining adequate ventilation, implementing effective cleaning practices, and conducting routine microbial monitoring to improve indoor air quality and protect the health of students, staff, and visitors within educational facilities.

6. Recommendations

1. Improve both natural and mechanical ventilation systems in classrooms, laboratories, administrative offices, and restrooms to enhance air exchange and reduce microbial accumulation.
2. Establish routine cleaning and disinfection programs targeting high-occupancy areas and frequently touched surfaces.
3. Conduct periodic maintenance of air-conditioning and ventilation systems to ensure optimal performance and indoor air circulation.
4. Promote awareness among students and staff regarding personal hygiene practices, particularly hand hygiene and respiratory etiquette.
5. Implement regular indoor air quality monitoring programs to detect changes in microbial contamination levels and identify potential health risks.
6. Expand future studies to include seasonal monitoring in order to evaluate the influence of climatic variables on airborne microbial populations.
7. Employ advanced microbial identification techniques, such as molecular and genomic methods, to improve the accuracy of bacterial characterization.
8. Continue monitoring antibiotic susceptibility patterns of environmental bacterial isolates to identify emerging antimicrobial resistance.
9. Develop institutional policies and environmental health management programs dedicated to maintaining healthy indoor learning environments.
10. Integrate indoor air quality assessment into university occupational health and safety strategies to support the well-being of students, academic staff, and employees.

References

1- Abu-Rub, L.I., et al., 2021. A preliminary study on microbial air contamination in select schools in Doha, Qatar. Arabian Journal of Geosciences, 14(24), p.2707.

2- Abhilasha Shourie , Anita Girdhar , Kriti Singhal , Chanchal Rawat , and Shilpa Samir Chapadgaonkar Biocontaminants in Indoor Environments Occurrence, Spread, and Prevention 2024 John Wiley & Sons, Inc. Published 2024 by John Wiley & Sons, Inc

3- Adams, R.I., Bhangar, S., Pasut, W., Arens, E.A., Taylor, J.W., Lindow, S.E., Nazaroff, W.W. and Bruns, T.D. (2015). Chamber Bioaerosol Study: Outdoor Air and Human Occupants as Sources of Indoor Airborne Microbes. PLoS ONE, 10(5), e0128022

4- American Society for Microbiology. Guidelines for Environmental Microbiology. 2023.

5- ASHRAE. (2024). Ventilation for Acceptable Indoor Air Quality.
CDC. (2024). Environmental Infection Control Guidelines.

6- Awada, M., et al. (2022). Indoor Air Quality in Educational Buildings: A Review. Building and Environment, 223, 109462.

7- Azimi, P., Stephens, B. (2023). Indoor Air Quality and Airborne Microbial Exposure in Educational Buildings. Building and Environment.

8- Branco, P. T. B. S., Sousa, S. I. V., Dudzińska, M. R., et al. (2024). A review of relevant parameters for assessing indoor air quality in educational facilities. Environmental Research, 261, 119713. https://doi.org/10.1016/j.envres.2024.119713 \

9- Correia, G., & Calheiros, D. (2025). Indoor air quality and airborne transmission under the One Health lens: A scoping review. One Health, 21, 101160187–200.

10- Dancer, S.J. (2022). Indoor Air and Microbial Contamination in Public Buildings. Journal of Hospital Infection.

11- Denina Hospodsky, Jing Qian,William W. Nazaroff,Naomichi Yamamoto,Kyle Bibby,Hamid Rismani-Yazdi, Jordan Peccia Human Occupancy as a Source of Indoor Airborne Bacteri Published: April 18, 2012 https://doi.org/10.1371/journal.pone.0034867

12- Ding, E., Zhang, D. and Bluyssen, P.M. (2022). Ventilation regimes of school classrooms against airborne transmission of infectious respiratory droplets: A review. Building and Environment, 207, 108484
13- Douwes, J., Thorne, P., Pearce, N. and Heederik, D. (2003). Bioaerosol health effects and exposure assessment: progress and prospects. Annals of Occupational Hygiene, 47(3), pp.
14- Dumont-Leblond, N., Veillette, M., Bhérer, L., Duchaine, C. and others (2020). Characterization of airborne bacteria and fungi from elementary school classrooms in an urban environment
15- Gilbert, J. A., & Hartmann, E. M. (2024). The indoors microbiome and human health. Nature Reviews Microbiology, 22(12), 742–755. https://doi.org/10.1038/s41579-024-01077-3
16- Gohli, J., et al. (2022). Airborne Microbial Diversity in University Classrooms. *Scientific Reports*, 12, 14567.
17- Grassie, D., Milczewska, K., Renneboog, S., Scuderi, F., & Dimitroulopoulou, S. (2025). Impact of indoor air quality, including thermal conditions, in educational buildings on health, wellbeing, and performance: A scoping review. Environments, 12(8), 261.
18- Hitikk Chawla , Purnima Anand , Kritika Garg , Neeru Bhagat , Shivani G. Varmani , Tanu Bansal , Andrew J. McBain and Ruchi Gulati Marwah Acomprehensive review of microbial contamination in the indoor environment: sources, sampling, health risks, and mitigation strategies , TYPE Review PUBLISHED 23 November 2023 DOI 10.3389/fpubh.2023.1285393
19- Hospodsky, D., Qian, J., Nazaroff, W.W., Yamamoto, N., Bibby, K., Rismani-Yazdi, H. and Peccia, J. (2012). Human Occupancy as a Source of Indoor Airborne Bacteria. PLoS ONE, 7(4), e34867.'
20- Foarde KK, Dulaney P, Cole E, Van Osdell D, Ensor D, Chang J. Assessment of fungal growth on ceiling tiles under environmentally characterized conditions. Indoor Air. 1993;4:357–362. [Google Scholar
21- Frankel, M., et al. (2023). Microbial Communities in Indoor Air and Their Impact on Human Health. *Environmental Research*, 216, 114674.
22- jones M, Harrison RM . (2004). The effects of meteorological factors on atmospheric bioaerosol concentrations - a review. *Sci Total Environ* **326**: 151–180.
23- Jung, W., et al. (2024). The relationship between occupancy density, ventilation rates, and indoor airborne bacterial concentrations in educational buildings. Journal of Building Engineering, 82, 108340.
24- Kalogerakis N, Paschali D, Lekaditis V, Pantidou A, Eleftheriadis K, Lazaridis M. Indoor air quality-bioaerosol measurements in domestic and office premises. J Aerosol Sci. 2005;36:751–761. [Google Scholar]
25- Kembel, S.W., Jones, E., Kline, J., Northcutt, D., Stenson, J., Womack, A.M., Bohannan, B.J.M., Brown, G.Z. and Green, J.L. (2012). Architectural design influences the diversity and structure of the built environment microbiome. The ISME Journal, 6(8), pp.1469–1479
26- Lax, S. et al. (2014). Longitudinal analysis of microbial interaction between humans and the indoor environment. Science, 345(6200), pp.1048–1052.
27- Labihi, A., et al., 2024. Assessment of the impact of ventilation in classrooms on indoor air quality and microbial load. Journal of Building and Environment, 248, p.111120.
28- Lee, H., Lee, B.G., Kim, Y.J., Shim, J.E. and Yeo, M.K. (2024). Assessment of airborne bacteria in the indoor of public-use facilities concentrated on influencing factors and opportunistic pathogenic bacteria. Air Quality, Atmosphere & Health, 17(8), pp.1725–1738

29- Li, Y., Qian, H. (2024). Bioaerosols in Indoor Environments: Sources, Health Effects and Control Strategies. *Environmental Research*.
30- Luongo, R., et al., 2023. The impact of ventilation systems on indoor air quality and microbial load in school environments. Building and Environment, 232, p.110045
31- Madureira, J., et al. (2020). Microbial Exposure Assessment in School Buildings. *Atmospheric Environment*, 224, 117307.
32- Meadow, J.F., Altrichter, A.E., Kembel, S.W., Kline, J., Mhuireach, G., Moriyama, M., Northcutt, D., O'Connor, T.K., Womack, A.M. and Brown, G.Z. (2014). Indoor airborne bacterial communities are influenced by ventilation, occupancy, and outdoor air source. Indoor Air, 24(1), pp.41–48.
33- Madsen , Saloomeh Moslehi-Jenabian,., Mika Frankel ., John Kerr White ., Margit W Frederiksen . Airborne bacterial species in indoor air and association with physical factors UCL Open Environ
. 2023 Mar 31;5:e056. doi: 10.14324/111.444/ucloe.000056
34- Morawska, L., Milton, D.K. (2022). Indoor Airborne Transmission of Microorganisms. Annual Review of Public Health.
35- Muhammad, A., 2025. Assessment of indoor microbial air quality in classrooms using passive air sampling method. Journal of Environmental Science and Technology, 19(2), pp.45-56.
36- Nguyen, T.T., Johnson, G.R., Bell, S.C. and Knibbs, L.D. (2022). A Systematic Literature Review of Indoor Air Disinfection Techniques for Airborne Bacterial Respiratory Pathogens. International Journal of Environmental Research and Public Health, 19(3), 1197.
37- Olusola-Makinde, O.O., Oladayo, M.K. and Oni, Y., 2022. Evaluation of indoor microbial air quality of government primary schools. Research Journal of Environmental Sciences, 16(1), pp.12-21
38- Pasquarella, C., Pitzurra, O. and Savino, A. (2000). The index of microbial air contamination. Journal of Hospital Infection, 46(4), pp.241–256
39- Pradeep Kumar · Mohd. Adnan Kausar · A. B. Singh Rajeev Singh Biological contaminants in the indoor air environment and their impacts on human health Received 4 January 2021 Air Quality, Atmosphere & Health (2021) 14:1723–1736
40- Prussin, A. J., & Marr, L. C. (2021). Sources of Airborne Microorganisms in Indoor Environments. *Microbiome*, 9(1), 1–14.
41- Purnima Anand , Kritika GargNeeru .,Bhagat Tanu, Bansal , Gulati Marwah A comprehensive review of microbial contamination in the indoor environment: sources, sampling, health risks, and mitigation strategies, 2023 Sec. Environmental Health and Exposome Volume 11 - 2023 | https://doi.org/10.3389/fpubh.2023.1285393.]
42- Qian J, Hospodsky D, Yamamoto N, Nazaroff WW, Peccia J. Size-resolved emission rates of airborne bacteria and fungi in an occupied classroom. Indoor Air. 2012;22:339–351. doi: 10.1111/j.1600-0668.2012.00769.x. [DOI] [PMC free article] [PubMed] [Google Scholar
43- Qian, J., Hospodsky, D., Yamamoto, N., Nazaroff, W.W. and Peccia, J. (2012). Size-resolved Emission Rates of Airborne Bacteria and Fungi in an Occupied Classroom. Indoor Air, 22(4), pp.339–351.
44- Almuntasir, S. Y., Elmuaget, H. M., ALtarabulsi, D. J., & Salah, A. B. (2026). The Impact of Environmental Awareness on Sustainable Water Conservation Behavior among Postgraduate Students: Field Study. *Al-Farooq Journal of Sciences*, *2*(4), 315-331.

45- Ruiz-Gil, JJ Acuña, S Fujiyoshi, D Tanaka, J Noda, F Maruyama, Airborne bacterial communities of outdoor environments and their associated influencing factors Environment International 145, 106156
46- Sandhya Rai, Dileep K. Singh, Amod Kumar Microbial, environmental and anthropogenic factors influencing the indoor microbiome of the built environment 01 February 2021 https://doi.org/10.1002/jobm.202000575Digital Object Identifier (DOI)
47- ALfordaga, M., & Omer, A. I. (2026). Real-Time Requirements Analysis in Smart Healthcare Monitoring Systems: A Case Study of an ATmega328P-Based Health Monitoring Device. *Al-Farooq Journal of Sciences*, *2*(3), 1216-1236.
48- Shailaja G.S.J., Meganathan P. Ramakodi & Ramakrishna T.V.B.P.S.Hospodsky D, Qian J, Nazaroff WW, Yamamoto N, Bibby K, Rismani-Yazdi H, et al. Human occupancy as a source of indoor airborne bacteria. PLoS One. 2012 doi: 10.1371/journal.pone.0034867. [DOI] [PMC free article] [PubMed] [Google Scholar]
49- Shin, H.W. and Kang, D.H. (2023). Estimation of airborne infection risk in a school classroom according to operation of a floor-standing type ventilation system. Journal of Building Engineering, 78, 107649.
50- Sneh Singh; Siddhant WaliaCorresponding Author; Himangshu Kedia Green spaces within the role of indoor plants in enhancing aesthetics, air quality and well-being Urbanization, Sustainability and Society (2026) 3 (2): 1–16. https://doi.org/10.1108/USS-12-2024-0098.
51- Steven W. Kembel., James F. Meadow., Timothy K. O'Connor, Gwynne Mhuireach, Dale Northcutt Jeff Kline , Maxwell Moriyama, G. Z. Brown, Brendan J. M. Bohannan, Jessica L. Green Architectural Design Drives the Biogeography of Indoor Bacterial Communities PLOS ONE www.plosone.org 1 January 2014 Volume 9 Issue 1 e8709
52- Taubel M, Rintala H, Pitkaranta M, Paulin L, Laitinen S, Pekkanen J, et al. The occupant as a source of house dust bacteria. J Allergy Clin Immunol. 2009;124:834–840. doi: 10.1016/j.jaci.2009.07.045. [DOI] [PubMed] [Google Scholar
53- Toyinbo, O., et al., 2023. Modeling the combined effects of ventilation rates and occupancy density on airborne microbial contamination in educational settings. Building and Environment, 235, p.110210.
54- Tantoush, J. A. M. (2025). Environmental Pollution Assessment of Some Heavy Metals in the Western Coast of Tripoli, Libya. *Al-Farooq Journal of Sciences*, *1*(1), 161-175.
55- Zhang, X. et al. (2023). Microbial Communities in University Buildings and Their Relationship with Occupancy and Ventilation. Science of the Total Environment.
56- Zulkifle, N. T., Wahab, M. I. A., Neoh, H. M., et al. (2025). Environmental factors attributed on dissemination of antibiotic-resistant bacteria (ARB) and antibiotic resistance genes (ARGs) through PM2.5 and PM10. Aerobiologia, 41, 569–590. https://doi.org/10.1007/s10453-025-09870-0
57- World Health Organization (WHO). (2023). Indoor Air Quality and Public Health.
58- World Health Organization. Global Air Quality Guidelines. 2021.