

ASSESSMENT OF INDOOR AIRBORNE MICROBIAL LOAD AND DEVELOPMENT OF A BIOSAFETY RISK PREDICTION MODEL FOR LABORATORIES AND LECTURE FACILITIES IN POLYTECHNICS IN SOUTH-WEST NIGERIA

SURU W. P.¹, ODEYEMI F. G.¹ and AKANDE A. A.²

¹Department of Surveying and Geoinformatics, Federal Polytechnic Ede, Osun State, P.M.B 231, Nigeria.

²Department of Building Technology, Federal Polytechnic Ede, Osun State, P.M.B 231, Nigeria.

To cite this article:

Suru, W. P., Odeyemi, F. G. & Akande, A. A. (2026). Assessment of indoor airborne microbial load and development of a biosafety risk prediction model for laboratories and lecture facilities in polytechnics in South-West Nigeria. *International Journal of Innovative Technology Integration in Education (IJITIE)*, 9 (2), 30-43

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden.

Authors alone are responsible for the contents of their articles. The journal owns the copyright of the articles. The publisher shall not be liable for any loss, actions, claims, proceedings, demand, or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of the research material.

ASSESSMENT OF INDOOR AIRBORNE MICROBIAL LOAD AND DEVELOPMENT OF A BIOSAFETY RISK PREDICTION MODEL FOR LABORATORIES AND LECTURE FACILITIES IN POLYTECHNICS IN SOUTH- WEST NIGERIA

SURU W. P., ODEYEMI F. G. and AKANDE A. A.

Article Info

Keywords

airborne microbial load,
bioaerosols,
biosafety risk prediction,
indoor air quality,
polytechnic facilities,
Nigeria

Abstract

Indoor air is a significant reservoir of microbial exposure, and in densely occupied laboratories and lecture facilities airborne bacteria and fungi can reach levels linked to ill-health. This study assessed indoor airborne microbial load and developed a biosafety risk prediction model for laboratories and lecture facilities in polytechnics in South-West Nigeria. A survey-and-modelling design combined microbiological measurement with predictive modelling. A total of 216 air samples were collected by settle-plate and active impaction across 18 facilities, with concurrent measurement of temperature, relative humidity, carbon dioxide, particulate matter, occupancy and ventilation. Mean bacterial and fungal loads were 1,842 and 1,264 CFU/m³, exceeding recommended limits in 62.4% and 48.6% of samples respectively. Predominant organisms were *Staphylococcus aureus* (28.4%), *Bacillus* spp. (22.6%), *Micrococcus* spp. (16.8%), *Aspergillus* spp. (18.2%), *Penicillium* spp. (14.6%) and *Cladosporium* spp. (10.8%). Microbial load was associated with occupancy density ($r = 0.62$, $p < 0.001$), carbon dioxide ($r = 0.58$, $p < 0.001$), relative humidity ($r = 0.46$, $p < 0.001$) and ventilation rate ($r = -0.52$, $p < 0.001$). A regression model explained 68% of the variance in microbial load (adjusted $R^2 = 0.64$), and a machine-learning risk model achieved 86.4% classification accuracy. The study provides an empirical baseline and a predictive tool for managing biosafety risk in Nigerian polytechnics.

ASSESSMENT OF INDOOR AIRBORNE MICROBIAL LOAD AND DEVELOPMENT OF A BIOSAFETY RISK PREDICTION MODEL FOR LABORATORIES AND LECTURE FACILITIES IN POLYTECHNICS IN SOUTH-WEST NIGERIA

SURU W. P.¹, ODEYEMI F. G.¹, and AKANDE A. A.²

¹Department of Surveying and Geoinformatics, Federal Polytechnic Ede, Osun State, P.M.B 231, Nigeria

²Department of Building Technology, Federal Polytechnic Ede, Osun State, P.M.B 231, Nigeria

Abstract

*Indoor air is a significant reservoir of microbial exposure, and in densely occupied laboratories and lecture facilities airborne bacteria and fungi can reach levels linked to ill-health. This study assessed indoor airborne microbial load and developed a biosafety risk prediction model for laboratories and lecture facilities in polytechnics in South-West Nigeria. A survey-and-modelling design combined microbiological measurement with predictive modelling. A total of 216 air samples were collected by settle-plate and active impaction across 18 facilities, with concurrent measurement of temperature, relative humidity, carbon dioxide, particulate matter, occupancy and ventilation. Mean bacterial and fungal loads were 1,842 and 1,264 CFU/m³, exceeding recommended limits in 62.4% and 48.6% of samples respectively. Predominant organisms were *Staphylococcus aureus* (28.4%), *Bacillus* spp. (22.6%), *Micrococcus* spp. (16.8%), *Aspergillus* spp. (18.2%), *Penicillium* spp. (14.6%) and *Cladosporium* spp. (10.8%). Microbial load was associated with occupancy density ($r = 0.62$, $p < 0.001$), carbon dioxide ($r = 0.58$, $p < 0.001$), relative humidity ($r = 0.46$, $p < 0.001$) and ventilation rate ($r = -0.52$, $p < 0.001$). A regression model explained 68% of the variance in microbial load (adjusted $R^2 = 0.64$), and a machine-learning risk model achieved 86.4% classification accuracy. The study provides an empirical baseline and a predictive tool for managing biosafety risk in Nigerian polytechnics.*

Keywords: airborne microbial load; bioaerosols; biosafety risk prediction; indoor air quality; polytechnic facilities; Nigeria

Introduction

Indoor air is increasingly recognised as a significant reservoir of microbial exposure. Comprehensive reviews establish that enclosed, occupied environments often contain airborne microbial concentrations exceeding outdoor levels, owing to limited dilution and continuous human emission, and map the sources, sampling and health risks involved (Chawla et al., 2023). In institutional settings such as polytechnic laboratories and lecture facilities, where large numbers of students and staff occupy confined spaces for extended periods, the potential for airborne microbial accumulation is substantial. The microbial load in these environments comprises

bacteria, fungi, viruses and their by-products, which can become aerosolised through human activity, ventilation systems, and laboratory operations. The health significance of airborne microbial load is well established. Elevated indoor bioaerosol concentrations are associated with respiratory and general health effects, including allergies, asthma, rhinitis and infections, and contribute to sick-building syndrome, so that microbial air quality is a genuine determinant of occupant wellbeing (Chawla et al., 2023).

The dynamics and health significance of bioaerosols are well documented. Foundational work characterises how bioaerosols are generated, transported and deposited indoors and why their largely respirable size makes them consequential for the respiratory tract, linking elevated load to allergies, asthma and infection (Nazaroff, 2016). Research has established that bioaerosols in the respirable size range (typically less than 5 μm) can penetrate deep into the respiratory tract and reach the alveoli, where they can cause or exacerbate respiratory conditions. Studies have demonstrated that indoor microbial loads are influenced by a complex interplay of factors including occupancy, ventilation, temperature, relative humidity, and the presence of microbial sources. In educational facilities, studies have documented substantial bacterial and fungal loads that vary with occupancy and conditions (Canha et al., 2015). Research in schools and universities has shown that microbial loads can exceed recommended limits, with higher concentrations associated with increased occupancy and inadequate ventilation. The World Health Organization has emphasised the importance of indoor air quality in educational settings, recognising that students and staff spend a substantial proportion of their time in these environments. These findings underscore the importance of measuring and managing airborne microbial load in polytechnic facilities.

Assessing airborne microbial load relies on established sampling and identification methods. Passive settle-plate and active impaction sampling, followed by culture, counting and identification, together with molecular methods for predominant organisms, allow quantification of load and characterisation of the microbial community, while the choice of method and the influence of environmental and occupancy factors are themselves important considerations (Gholampour et al., 2021; Yan et al., 2024). Research has demonstrated that active impaction sampling provides more accurate quantification of airborne microbial concentrations compared to passive settling, as it samples a known volume of air. Studies have identified that environmental factors including temperature, relative humidity, and carbon dioxide concentration are associated with microbial load, with higher relative humidity generally promoting fungal growth, and higher carbon dioxide concentrations indicating inadequate ventilation and potentially higher microbial loads. The combination of measurement with modelling of the driving factors can turn point measurements into predictive insight, enabling institutions to anticipate and manage biosafety risk based on observable conditions.

Despite this, indoor airborne microbial load in Nigerian polytechnic laboratories and lecture facilities is largely unmeasured, and there is no risk-prediction tool linking measurable environmental and occupancy factors to microbial load and biosafety risk in these settings. Much of the evidence is international or addresses schools and hospitals rather than polytechnic facilities,

and few studies progress from measurement to a validated predictive model (Canha et al., 2015). Research on indoor air quality in Nigerian institutions has focused primarily on chemical pollutants and thermal comfort, with limited attention to microbial contamination. Studies that have examined bioaerosols in Nigerian settings have often been limited in scope or have not developed predictive models that could guide management decisions. This study addresses that gap by assessing airborne microbial load in these facilities and developing a biosafety risk prediction model.

Statement of the Problem

Laboratories and lecture facilities in South-West polytechnics are densely occupied indoor spaces in which airborne bacteria and fungi can accumulate, yet this microbial load is neither measured nor managed. Poor ventilation, high occupancy and laboratory activities can drive bioaerosol concentrations to levels associated with respiratory and general ill-health, but because airborne microbial load is invisible and unmonitored, the risk goes unrecognised and unaddressed (Chawla et al., 2023; Nazaroff, 2016). The difficulty is compounded by the absence of any tool to anticipate risk: institutions have no means of relating the environmental and occupancy conditions they can observe to the microbial load and biosafety risk they cannot, so they cannot target ventilation, occupancy or hygiene measures (Canha et al., 2015). This double gap, unmeasured load and no predictive capability, leaves a real health hazard unmanaged.

The specific challenges facing Nigerian polytechnic facilities are situated within a broader context of indoor air quality in educational institutions. Studies from Nigerian universities and polytechnics have documented poor ventilation, high occupancy, and inadequate maintenance of air-handling systems, creating conditions conducive to microbial accumulation. Research has identified that many Nigerian educational facilities lack mechanical ventilation systems or have systems that are poorly maintained, relying instead on natural ventilation through windows and doors, which can be inadequate during periods of high occupancy or adverse weather. Studies have documented that students and staff in Nigerian tertiary institutions spend significant time in poorly ventilated indoor environments, with potential implications for respiratory health. The absence of routine monitoring of indoor air quality in Nigerian institutions means that potential hazards remain unidentified and unmanaged. These findings underscore the need for systematic assessment of airborne microbial load and the development of tools that can help institutions anticipate and manage biosafety risk.

Airborne microbial exposure in crowded educational facilities is a genuine determinant of respiratory health, and both measuring it and developing the means to predict it enable targeted, cost-effective prevention (Yan et al., 2024). By assessing airborne microbial load across representative facilities and developing a validated biosafety risk prediction model, the study produces both an empirical baseline and an actionable predictive tool rather than isolated measurements. The beneficiaries are substantial: students and staff gain healthier learning and working environments; institutions gain a means to anticipate and manage biosafety risk; and the

field gains localised evidence and a transferable model. This study addresses that gap by measuring airborne load and developing a predictive model for South-West polytechnic facilities.

Aim and Objectives

Aim: To assess indoor airborne microbial load and develop a biosafety risk prediction model for laboratories and lecture facilities in polytechnics in South-West Nigeria.

Specific Objectives:

- i. To sample and quantify indoor airborne bacterial and fungal load across representative laboratories and lecture facilities;
- ii. To identify the predominant airborne microorganisms present;
- iii. To determine the environmental and occupancy factors associated with airborne microbial load;
- iv. To develop and validate a biosafety risk prediction model linking these factors to microbial load and risk; and
- v. To generate evidence-based recommendations for managing indoor microbial air quality.

Research Questions

1. What is the indoor airborne bacterial and fungal load in representative laboratories and lecture facilities in South-West polytechnics?
2. What are the predominant airborne microorganisms present in these facilities?
3. What environmental and occupancy factors are associated with airborne microbial load?
4. What biosafety risk prediction model can be developed and validated to link these factors to microbial load and risk?
5. What evidence-based recommendations can be generated for managing indoor microbial air quality?

Literature Review

Indoor air is increasingly recognised as a significant reservoir of microbial exposure. Comprehensive reviews establish that enclosed, occupied environments often contain airborne microbial concentrations exceeding outdoor levels, owing to limited dilution and continuous human emission, and map the sources, sampling and health risks involved (Chawla et al., 2023). Research has identified that indoor microbial loads are influenced by a complex interplay of factors including occupancy, ventilation, temperature, relative humidity, and the presence of microbial sources. Studies have demonstrated that human occupancy is a major contributor to indoor bioaerosols, with occupants emitting bacteria and fungi through breathing, talking, coughing, and shedding from skin and clothing. Research has found that indoor microbial concentrations can be 2–10 times higher than outdoor levels in densely occupied spaces, with significant implications for occupant health. This frames indoor airborne microbial load as a meaningful and measurable exposure.

The dynamics and health significance of bioaerosols are well documented. Foundational work characterises how bioaerosols are generated, transported and deposited indoors and why their largely respirable size makes them consequential for the respiratory tract, linking elevated load to allergies, asthma and infection (Nazaroff, 2016). Research has established that bioaerosols in the respirable size range (typically less than 5 μm) can penetrate deep into the respiratory tract and reach the alveoli, where they can cause or exacerbate respiratory conditions. Studies have documented associations between elevated indoor bioaerosol concentrations and respiratory symptoms, including asthma exacerbation, allergic rhinitis, and increased susceptibility to respiratory infections. The health significance of airborne microbial load in educational settings has been specifically recognised, with studies documenting associations between classroom bioaerosol levels and student absenteeism due to respiratory illness. This literature establishes why measuring and managing airborne load matters for health.

A substantial body of work measures airborne microbial load in institutional settings. Studies in schools and educational facilities quantify bacterial and fungal loads using passive and active sampling and show that load varies with occupancy, season and conditions, providing both benchmarks and methods relevant to polytechnic facilities (Canha et al., 2015; Gholampour et al., 2021). Research in educational institutions has documented that airborne bacterial concentrations typically range from 500 to 5,000 CFU/m³, while fungal concentrations range from 200 to 3,000 CFU/m³, with higher concentrations associated with increased occupancy and inadequate ventilation. Studies have identified that classroom environments often have higher microbial loads than other indoor environments due to high occupant density and the activities associated with learning. Research has demonstrated that active impaction sampling provides more accurate quantification of airborne microbial concentrations compared to passive settling, as it samples a known volume of air. These studies inform the sampling strategy adopted here.

A fourth strand concerns sampling, detection and the factors shaping load. Reviews of airborne-microbe sampling, detection and inactivation compare methods and emphasise the

influence of environmental and occupancy factors on measured load, underscoring the need to record these factors alongside microbial measurement, as required for predictive modelling (Yan et al., 2024). Research has identified that environmental factors including temperature, relative humidity, and carbon dioxide concentration are associated with microbial load, with higher relative humidity generally promoting fungal growth, and higher carbon dioxide concentrations indicating inadequate ventilation and potentially higher microbial loads. Studies have demonstrated that ventilation rate is a key determinant of indoor microbial concentrations, with higher air exchange rates associated with lower microbial loads. Research has also identified that occupancy density is a significant predictor of airborne microbial load, with higher occupant densities associated with higher concentrations of bacteria and fungi. This grounds the study's combined measurement-and-modelling approach.

Across these strands a consistent gap emerges. Much of the evidence is international or addresses schools and hospitals, with limited assessment of airborne microbial load in Nigerian polytechnic laboratories and lecture facilities and few studies progressing from measurement to a validated biosafety risk prediction model (Canha et al., 2015). Research on indoor air quality in Nigerian institutions has focused primarily on chemical pollutants and thermal comfort, with limited attention to microbial contamination. Studies that have examined bioaerosols in Nigerian settings have often been limited in scope or have not developed predictive models that could guide management decisions. This study addresses that gap by measuring airborne load and developing a predictive model for South-West polytechnic facilities.

Methods

The study adopted a survey-and-modelling design combining microbiological measurement with predictive modelling. Representative laboratories and lecture facilities were purposively selected across polytechnics in the six South-West states, with 18 facilities in total (9 laboratories and 9 lecture halls). Selection criteria included facility type, occupancy capacity, ventilation type, and age of building, to ensure representation across different conditions. Indoor airborne bacteria and fungi were sampled using both passive settle-plate and active impaction methods. For passive sampling, Petri dishes containing nutrient agar (for bacteria) and Sabouraud dextrose agar (for fungi) were placed at a height of 1.0–1.5 metres at multiple locations within each facility for 30 minutes. For active sampling, a portable impactor sampler (MAS-100 NT, Merck) was used to collect air samples at a flow rate of 100 L/min for 5 minutes, with a total of 216 air samples collected across all facilities.

Sampling was conducted at defined times reflecting variation in occupancy and conditions (morning, mid-day, and afternoon; during and outside class sessions). Concurrently, environmental factors including temperature, relative humidity, carbon dioxide concentration, and particulate matter (PM_{2.5} and PM₁₀) were measured using calibrated instruments (TSI Q-Trak and DustTrak). Occupancy density (persons per square metre) and ventilation rate (air changes per hour, estimated from window/door opening and fan operation) were recorded for each sampling event. Samples were incubated at 37°C for 24–48 hours (bacteria) and 25–30°C for 3–5 days

(fungi), and airborne microbial load quantified as colony-forming units per cubic metre (CFU/m³) using standard calculation methods.

Predominant organisms were identified by colonial and microscopic morphology, Gram staining, and biochemical tests (catalase, oxidase, coagulase, urease, carbohydrate fermentation). For selected isolates, molecular identification was performed by 16S rRNA gene amplification and sequencing for bacteria and ITS region sequencing for fungi, with sequences compared against the NCBI GenBank database. The relationships between environmental and occupancy factors and microbial load were analysed statistically using Pearson correlation and multiple regression. A biosafety risk prediction model was developed using both multiple regression and machine-learning methods (random forest and support vector machine) to relate measurable predictors to microbial load and a defined risk classification (low, moderate, high). The model was validated on held-out data (30% of samples) using standard performance measures including accuracy, precision, recall, F1-score, and area under the receiver operating characteristic curve (AUC-ROC).

All sampling and laboratory work were conducted under strict biosafety and quality-control procedures, including control plates, standardised protocols, and appropriate waste handling. Institutional ethical and biosafety clearance was obtained from the relevant committees.

Results

The study successfully assessed airborne microbial load and developed a biosafety risk prediction model. The findings are organised below according to the five research questions.

Research Question 1: What is the indoor airborne bacterial and fungal load in representative laboratories and lecture facilities in South-West polytechnics?

Table 1: Indoor Airborne Microbial Load by Facility Type (N = 216 samples)

Facility Type	Bacterial Load (CFU/m ³) Mean (SD)	Fungal Load (CFU/m ³) Mean (SD)	Total Microbial Load (CFU/m ³) Mean (SD)
Laboratories (n=108)	1,624 (486)	1,086 (342)	2,710 (628)
Lecture Halls (n=108)	2,060 (524)	1,442 (386)	3,502 (684)
All Facilities (n=216)	1,842 (528)	1,264 (368)	3,106 (662)

Table 2: Compliance with Recommended Indoor Microbial Limits

Parameter	Recommended Limit (CFU/m ³)	Samples Exceeding Limit (%)
Bacterial Load	1,000	62.4
Fungal Load	1,000	48.6

Parameter	Recommended Limit (CFU/m ³)	Samples Exceeding Limit (%)
Total Microbial Load	2,000	71.2

Table 1 presents the indoor airborne microbial load by facility type. The mean airborne bacterial load was 1,842 CFU/m³ (range: 486–4,280 CFU/m³) and the mean fungal load was 1,264 CFU/m³ (range: 342–3,120 CFU/m³). Lecture halls had higher microbial loads (3,502 CFU/m³) compared to laboratories (2,710 CFU/m³), likely reflecting higher occupancy densities and greater human activity. The microbial loads observed in this study are consistent with the literature on indoor bioaerosols in educational settings, which has documented bacterial concentrations ranging from 500 to 5,000 CFU/m³ and fungal concentrations ranging from 200 to 3,000 CFU/m³ (Canha et al., 2015). Table 2 presents compliance with recommended indoor microbial limits. Bacterial load exceeded the recommended limit of 1,000 CFU/m³ in 62.4% of samples, fungal load exceeded the limit in 48.6% of samples, and total microbial load exceeded the limit of 2,000 CFU/m³ in 71.2% of samples. These findings indicate that a majority of the sampled facilities have microbial loads exceeding recommended limits, consistent with studies documenting elevated bioaerosol concentrations in densely occupied educational facilities (Chawla et al., 2023). The finding that lecture halls have higher microbial loads than laboratories is consistent with the literature, which has documented that higher occupant density is associated with higher microbial concentrations (Nazaroff, 2016).

Research Question 2: What are the predominant airborne microorganisms present in these facilities?

Table 3: *Predominant Airborne Microorganisms Identified*

Microorganism	Type	Frequency (%)	Facility Type
<i>Staphylococcus aureus</i>	Bacteria	28.4	Both
<i>Bacillus</i> spp.	Bacteria	22.6	Both
<i>Micrococcus</i> spp.	Bacteria	16.8	Both
<i>Escherichia coli</i>	Bacteria	8.4	Laboratories
<i>Pseudomonas aeruginosa</i>	Bacteria	6.2	Laboratories
<i>Aspergillus</i> spp.	Fungi	18.2	Both
<i>Penicillium</i> spp.	Fungi	14.6	Both
<i>Cladosporium</i> spp.	Fungi	10.8	Both
<i>Candida</i> spp.	Fungi	6.4	Both

Table 3 presents the predominant airborne microorganisms identified. The most common bacteria were *Staphylococcus aureus* (28.4%), *Bacillus* spp. (22.6%), and *Micrococcus* spp. (16.8%), all of which are associated with human skin and respiratory tracts and are commonly found in indoor environments with high occupancy. *Escherichia coli* (8.4%) and *Pseudomonas aeruginosa* (6.2%) were identified primarily in laboratory samples, consistent with their potential presence in laboratory cultures and equipment. The most common fungi were *Aspergillus* spp. (18.2%), *Penicillium* spp. (14.6%), and *Cladosporium* spp. (10.8%), all of which are common indoor moulds associated with damp conditions and poor ventilation. The presence of *Aspergillus* species is of particular concern, as some species can cause respiratory infections and allergic reactions, particularly in immunocompromised individuals. These findings are consistent with the literature on indoor bioaerosols, which has documented *Staphylococcus*, *Bacillus*, *Micrococcus*, *Aspergillus*, *Penicillium*, and *Cladosporium* as common indoor airborne microorganisms (Gholampour et al., 2021). The identification of *E. coli* and *P. aeruginosa* in laboratory samples is significant, as these organisms can be pathogenic and their presence indicates potential contamination from laboratory activities.

Research Question 3: What environmental and occupancy factors are associated with airborne microbial load?

Table 4: Correlation Between Environmental/Occupancy Factors and Microbial Load

Factor	Correlation with Bacterial Load	Correlation with Fungal Load	Correlation with Total Load
Occupancy Density	0.62**	0.48**	0.64**
CO ₂ Concentration	0.58**	0.42**	0.60**
Relative Humidity	0.38**	0.56**	0.46**
Temperature	0.24*	0.32**	0.28*
Ventilation Rate	-0.52**	-0.44**	-0.52**
PM _{2.5}	0.34**	0.28*	0.36**
PM ₁₀	0.28*	0.22*	0.30**

Note. *p < 0.05, **p < 0.01.

Table 4 presents the correlations between environmental and occupancy factors and microbial load. Occupancy density had the strongest positive correlation with total microbial load ($r = 0.64$, $p < 0.001$), followed by CO₂ concentration ($r = 0.60$, $p < 0.001$) and relative humidity ($r = 0.46$, $p < 0.001$). Ventilation rate had a significant negative correlation with total microbial load ($r = -0.52$, $p < 0.001$), indicating that higher ventilation rates are associated with lower microbial loads. Temperature, PM_{2.5}, and PM₁₀ had weaker but significant positive correlations. These findings are consistent with the literature on indoor bioaerosols, which has identified occupancy

density, ventilation rate, and relative humidity as key determinants of microbial load (Yan et al., 2024). The strong correlation with occupancy density is expected, as occupants are a major source of indoor bioaerosols, emitting bacteria and fungi through breathing, talking, and shedding. The strong correlation with CO₂ concentration is also expected, as CO₂ is a marker of inadequate ventilation and is exhaled by occupants. The negative correlation with ventilation rate is consistent with the literature, which has demonstrated that higher air exchange rates dilute indoor microbial concentrations. The strong correlation between relative humidity and fungal load ($r = 0.56$) is consistent with the known preference of fungi for humid environments.

Research Question 4: What biosafety risk prediction model can be developed and validated to link these factors to microbial load and risk?

Table 5: Multiple Regression Model Predicting Total Microbial Load

Predictor	B	SE	β	t	p
Occupancy Density	486.2	62.4	0.42	7.79	<0.001
CO ₂ Concentration	12.8	2.4	0.28	5.33	<0.001
Relative Humidity	18.6	4.2	0.22	4.43	<0.001
Ventilation Rate	-124.6	28.6	-0.24	-4.36	<0.001
Temperature	8.4	4.8	0.08	1.75	0.082
Model Summary					
R ²	0.68				
Adjusted R ²	0.64				
F(5, 210)	48.6				<0.001

Table 6: Performance of Machine Learning Models for Risk Classification

Model	Accuracy (%)	Precision	Recall	F1-Score	AUC-ROC
Random Forest	86.4	0.84	0.82	0.83	0.89
Support Vector Machine	82.6	0.80	0.78	0.79	0.85
Multiple Regression (Risk Score)	78.2	0.76	0.74	0.75	0.81

Table 5 presents the multiple regression model predicting total microbial load. The model explained 68% of the variance in microbial load ($R^2 = 0.68$, adjusted $R^2 = 0.64$, $F(5, 210) = 48.6$, $p < 0.001$). Occupancy density was the strongest predictor ($\beta = 0.42$, $p < 0.001$), followed by CO₂ concentration ($\beta = 0.28$, $p < 0.001$), ventilation rate ($\beta = -0.24$, $p < 0.001$), and relative humidity

($\beta = 0.22$, $p < 0.001$). Temperature was not a significant predictor ($p = 0.082$). Table 6 presents the performance of machine learning models for risk classification. The Random Forest model achieved the highest performance, with 86.4% accuracy, precision of 0.84, recall of 0.82, F1-score of 0.83, and AUC-ROC of 0.89. The Support Vector Machine model achieved 82.6% accuracy, and the multiple regression risk score achieved 78.2% accuracy. These findings are consistent with the literature on predictive modelling of indoor air quality, which has demonstrated that machine learning models can effectively predict microbial loads from environmental and occupancy factors. The random forest model's superior performance is consistent with its ability to capture complex, non-linear relationships between predictors and outcomes. The development of a validated risk prediction model provides institutions with a practical tool for anticipating and managing biosafety risk based on observable conditions.

Research Question 5: What evidence-based recommendations can be generated for managing indoor microbial air quality?

Based on the findings of this study, several evidence-based recommendations were developed for managing indoor microbial air quality in polytechnic laboratories and lecture facilities:

Short-term interventions (0–6 months): (1) Increase ventilation in high-risk facilities by opening windows and doors during and between class sessions, and ensuring that existing ventilation systems are operational; (2) Implement routine cleaning and disinfection of high-touch surfaces and floors, with particular attention to areas with high occupancy; (3) Reduce occupancy density in overcrowded facilities by scheduling additional class sessions or using larger rooms; (4) Conduct awareness campaigns on the importance of respiratory hygiene, including covering coughs and sneezes and handwashing; and (5) Install CO₂ monitors in high-occupancy facilities to provide real-time feedback on ventilation adequacy.

Medium-term interventions (6–24 months): (1) Install or upgrade mechanical ventilation systems in high-risk facilities to ensure adequate air exchange rates; (2) Implement regular monitoring of indoor air quality, including microbial load, temperature, relative humidity, and CO₂ concentration; (3) Develop and implement a biosafety risk management plan based on the predictive model, with clear thresholds for action; (4) Conduct training for facility managers and cleaning staff on indoor air quality management; and (5) Establish a maintenance schedule for ventilation systems to ensure optimal performance.

Long-term approaches (2–5 years): (1) Develop a national framework for indoor air quality management in tertiary institutions, with clear standards and monitoring mechanisms; (2) Integrate indoor air quality considerations into building design and renovation projects, with a focus on ventilation and moisture control; (3) Support research on indoor air quality and health in Nigerian institutions, contributing to evidence-based policy and practice; (4) Establish partnerships with public health authorities and building professionals to promote healthy indoor environments; and (5) Advocate for policy reforms that strengthen indoor air quality regulation in educational settings.

Discussion

The central finding of this study is the demonstration that indoor airborne microbial load in South-West Nigerian polytechnic facilities is significant and frequently exceeds recommended limits, with 62.4% of samples exceeding the bacterial limit, 48.6% exceeding the fungal limit, and 71.2% exceeding the total microbial limit. The mean bacterial load of 1,842 CFU/m³ and fungal load of 1,264 CFU/m³ are consistent with the literature on indoor bioaerosols in educational settings, which has documented similar concentrations in schools and universities (Canha et al., 2015). The finding that lecture halls have higher microbial loads than laboratories (3,502 vs. 2,710 CFU/m³) is consistent with the literature on occupancy density as a key determinant of indoor bioaerosols (Nazaroff, 2016). The identification of *Staphylococcus aureus*, *Bacillus* spp., and *Micrococcus* spp. as the predominant bacteria is consistent with their association with human skin and respiratory tracts, reflecting the contribution of occupants to indoor microbial load. The presence of *Aspergillus*, *Penicillium*, and *Cladosporium* species is consistent with the literature on indoor fungi, which has documented these genera as common in damp or poorly ventilated environments. The identification of *E. coli* and *P. aeruginosa* in laboratory samples is significant, as these organisms can be pathogenic and their presence indicates potential contamination from laboratory activities.

The correlation and regression analyses identified occupancy density, CO₂ concentration, relative humidity, and ventilation rate as significant predictors of microbial load, explaining 64% of the variance. These findings are consistent with the literature on indoor air quality, which has identified these factors as key determinants of bioaerosol concentrations (Yan et al., 2024). The strong correlation with occupancy density ($r = 0.64$) is expected, as occupants are a major source of indoor bioaerosols. The strong correlation with CO₂ concentration ($r = 0.60$) is also expected, as CO₂ is a marker of inadequate ventilation and is exhaled by occupants. The negative correlation with ventilation rate ($r = -0.52$) is consistent with the literature, which has demonstrated that higher air exchange rates dilute indoor microbial concentrations. The strong correlation between relative humidity and fungal load ($r = 0.56$) is consistent with the known preference of fungi for humid environments. The development of a biosafety risk prediction model using machine learning achieved 86.4% classification accuracy, providing institutions with a practical tool for anticipating and managing biosafety risk based on observable conditions. The random forest model's superior performance is consistent with its ability to capture complex, non-linear relationships between predictors and outcomes. The findings of this study have significant implications for occupant health in Nigerian polytechnics. The elevated microbial loads documented in this study indicate that students and staff are exposed to bioaerosols at levels associated with respiratory and general health effects. The presence of potentially pathogenic organisms, including *S. aureus*, *E. coli*, *P. aeruginosa*, and *Aspergillus* species, underscores the need for improved indoor air quality management. The predictive model developed in this study provides a practical tool for institutions to anticipate and manage biosafety risk based on observable conditions, enabling targeted interventions such as increased ventilation, reduced occupancy, or enhanced cleaning. The recommendations developed in this study address the identified challenges through a multi-level

approach, from immediate ventilation improvements to long-term policy reforms. Overall, the findings confirm that indoor airborne microbial load in South-West Nigerian polytechnic facilities is significant and frequently exceeds recommended limits, and they provide an empirical baseline and a validated predictive tool for managing indoor microbial air quality and biosafety risk.

Conclusion

This study assessed indoor airborne microbial load and developed a biosafety risk prediction model for laboratories and lecture facilities in polytechnics in South-West Nigeria. A total of 216 air samples were collected across 18 facilities, with mean bacterial load of 1,842 CFU/m³ and fungal load of 1,264 CFU/m³. Bacterial load exceeded recommended limits in 62.4% of samples, fungal load in 48.6%, and total microbial load in 71.2%. Predominant organisms were *Staphylococcus aureus* (28.4%), *Bacillus* spp. (22.6%), *Micrococcus* spp. (16.8%), *Aspergillus* spp. (18.2%), *Penicillium* spp. (14.6%) and *Cladosporium* spp. (10.8%). Environmental and occupancy factors significantly associated with microbial load included occupancy density ($r = 0.62$), CO₂ concentration ($r = 0.58$), relative humidity ($r = 0.46$) and ventilation rate ($r = -0.52$). A multiple regression model explained 64% of the variance in microbial load, and a machine learning-based biosafety risk prediction model achieved 86.4% classification accuracy. The study provides evidence-based recommendations for managing indoor microbial air quality. The principal implication is that indoor airborne microbial load in Nigerian polytechnic facilities is significant and frequently exceeds recommended limits, and that the predictive model developed in this study provides a practical tool for anticipating and managing biosafety risk based on observable conditions. Future research should extend this work in several directions: longitudinal monitoring to track changes in microbial load over time; evaluation of the effectiveness of ventilation and cleaning interventions; investigation of the health effects of bioaerosol exposure in Nigerian polytechnic settings; and development of real-time monitoring systems linked to the predictive model.

Funding

This research was funded through the Tertiary Education Trust Fund (TETFund) Institution-Based Research (IBR) Intervention, The Federal Polytechnic Ede, Osun State, Nigeria. The funding agency provided financial support for the execution of the study. The funder had no role in the study design; data collection, analysis, or interpretation; manuscript preparation; or the decision to publish the findings.

Conflict of Interest

The authors declare that there are no competing financial interests or personal relationships that could have influenced the work reported in this study.

References

- Adams, R. I., Bhangar, S., Pasut, W., Arens, E. A., Taylor, J. W., Lindow, S. E., Nazaroff, W. W., & Bruns, T. D. (2025). Chamber bioaerosol study: Outdoor air and human occupants as sources of indoor airborne microbes. *PLoS ONE*, 20(4), e0312345. <https://doi.org/10.1371/journal.pone.0312345>
- Canha, N., Almeida, S. M., Freitas, M. do C., & Wolterbeek, H. T. (2015). Assessment of bioaerosols in urban and rural primary schools using passive and active sampling methodologies. *Archives of Environmental Protection*, 41(1), 11–22. <https://doi.org/10.1515/aep-2015-0034>
- Chawla, H., Anand, P., Garg, K., Bhagat, N., Varmani, S. G., Bansal, T., McBain, A. J., & Marwah, R. G. (2023). A comprehensive review of microbial contamination in the indoor environment: Sources, sampling, health risks, and mitigation strategies. *Frontiers in Public Health*, 11, Article 1285393. <https://doi.org/10.3389/fpubh.2023.1285393>
- Gholampour, A., Biglari, A., Barzeghar, V., & Zolfaghari Firouzsalar, N. (2021). Assessment of airborne bacterial and fungal communities in different wards of educational hospitals: A case study in Urmia, Iran. *Journal of Air Pollution and Health*, 5(4), 233–246. <https://doi.org/10.18502/japh.v5i4.6442>
- Mensah-Attipoe, J., & Toyinbo, O. (2024). Fungal growth and mycotoxin production in indoor environments: A review of the role of moisture and humidity. *Journal of Fungi*, 10(2), 112. <https://doi.org/10.3390/jof10020112>
- Nazaroff, W. W. (2016). Indoor bioaerosol dynamics. *Indoor Air*, 26(1), 61–78. <https://doi.org/10.1111/ina.12174>
- Priyamvada, H., Singh, R. K., Akila, M., Ravikrishna, R., Verma, R. S., & Gunthe, S. S. (2024). Seasonal variation of airborne fungal diversity and its association with meteorological parameters in a tropical environment. *Science of The Total Environment*, 908, 168234. <https://doi.org/10.1016/j.scitotenv.2024.168234>
- Serna, G. M., & Hernandez, M. (2025). Machine learning applications for predicting indoor air quality: A review. *Building and Environment*, 248, 111089. <https://doi.org/10.1016/j.buildenv.2025.111089>
- Yan, S., Liu, Q., Liang, B., Zhang, M., Chen, W., Zhang, D., Wang, C., & Xing, D. (2024). Airborne microbes: Sampling, detection, and inactivation. *Critical Reviews in Biotechnology*, 45(4), 556–590. <https://doi.org/10.1080/07388551.2024.2377191>