

Research Article

Microbial Indoor Air Pollution of Buildings at Al-Karkh University of Science/ Abu Ghraib, Iraq

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Article Information

Abstract



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Indoor air pollution causes many diseases and health complications. According to the World Health Organization, air pollution is responsible for the premature death of 7 million people. The aim of the current study was to estimate the airborne microorganisms, noise, and chemical hazards for indoor air quality in the buildings of Al-Karkh University of Science. One hundred ninety-two samples were collected by open plate and exposed to the air for 60 min, and 192 samples were swabbed from hard surfaces. Air samples collected from various buildings of Al-Karkh University of Science revealed clear seasonal variations in indoor air quality. The maximum microbial load showed in the buildings of the College of Energy and Environmental Sciences and the College of Science, particularly in January. The major microbial species were *Staphylococcus aureus* and *Bacillus* spp., with increased fungal growth during the winter season, with *Aspergillus niger* and *Penicillium*. Noise levels were up to 75 dB and maximum concentrations of H₂S and CO were observed during the month of January. A significant depletion of oxygen (0.1-1.5%) and high levels of flammable gases (11-25%) were also observed, particularly during the winter months. Indoor environments in Iraq are exposed to multiple sources of overlapping pollutants that place a significant burden on public health. Measured excess of WHO and EPA limits for noise, CO, and bioaerosol prevalence require urgent mitigation efforts.



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1. INTRODUCTION

Bacteria and fungi are widespread microorganisms that can withstand high temperatures, pressure, radiation, salinity, darkness, and cold. The components of atmospheric air include oxygen, nitrogen, carbon dioxide, trace gases, inorganic particles, and biologically generated compounds [1]. Because most people spend their time indoors, indoor air quality has grown to be a significant public health concern. Maintaining human health and general well-being critically depends on the quality of air in homes, workplaces, classrooms, laboratories, and other public or private structures [2]. Because closed enclosures allow aerosols to accumulate to potentially infectious proportions, microorganisms are one of the primary causes of indoor air pollution [3]. Bacteria and molds are mostly caused microbiological degradation in both indoor and outdoor settings. By converting organic matter into reusable metabolites, they play a crucial role in biogeochemical cycles. Bacterial and fungal spores are common in the air and can infiltrate buildings through air exchange or passive ventilation [4]. As shown by Capanna [5], environmental conditions like high humidity and high-water content in building materials encourage microbial growth even though many microbial species are part of the natural flora and are not intrinsically dangerous. Spallanzani's investigations in the middle of the 18th century proved the existence of microbes in the atmosphere, and Pasteur's research in the 19th century corroborated this [6].

Microorganisms naturally exist in the atmosphere between 300 and 10,000 feet above the surface of the earth, according to Pasteur. In both polar and non-polar air masses, fungal spores such as *Alternaria*, *Cladosporium*, *Penicillium*, and *Aspergillus* have been found at elevations more than 4,000 feet [7]. Because indoor surroundings can be impacted by a variety of elements, including bacteria, pollen, smoke, humidity, and chemical emissions from human activity, indoor air pollution poses a serious threat to human health [8]. Numerous studies have highlighted how global warming is increasingly affecting human health by raising air pollution levels. Pollen and airborne pollution concentrations have significantly increased in recent decades, increasing the prevalence of allergy diseases such as asthma, conjunctivitis, and rhinitis [9]. *Aspergillus* species are known to be pathogenic fungi that can cause harm to people because of their potential for infection as well as their poisonous and allergic qualities.



Depending on a person's immune system, breathing in *Aspergillus* spores might cause respiratory issues, including invasive pulmonary aspergillosis or allergic asthma [9]. On the other hand, *P. species* are among the most prevalent airborne fungi and are usually not harmful; however, they can cause serious infections or even death in those with weakened immune systems [10]. Sick building syndrome (SBS) has been associated with exposure to high concentrations of mixed organic dust, which includes mycotoxins, volatile organic compounds (VOCs), and allergens including glucans [11].

Many studies have documented an upsurge in health problems associated with indoor airborne fungi throughout the last 20 years. A number of causes could be responsible for this increase, such as increased time spent indoors, the rise in opportunistic fungus species, and the rise in immune system abnormalities and chronic illnesses [12]. Alpha-aminoisobutyric acid (up to 10% w/w) is one of the uncommon amino acids found in tiny poisonous peptides known as trilogins, which are produced by the common indoor mold *Trichoderma longibrachiatum*. By entering human cells and creating nanoscale channels that obstruct vital ion transport pathways of potassium and sodium across cellular membranes, these substances demonstrate toxicity [13].

This disturbance causes conduction anomalies by changing the action potential of different cells, including neurons, pneumocytes, and cardiomyocytes. Since trilogins are very resistant to heat and antibiotics, prevention is the main strategy to lessen their impact [14]. The present study aims to perform both quantitative and qualitative assessments of airborne microorganisms in buildings located at Al-Karkh University of Science in Abu Ghraib, as well as to examine their seasonal variations..

2. METHODS

2.1 Samples collection

The study was conducted to detect microbial contamination of the indoor air in the buildings of Al-Karkh University of Science, including:

Building A: College of Science and College of Energy and Environmental Sciences

Building B: Directorate of Internal Departments

Building C: building of student activities

Building D: internal departments for females

Building E: internal departments for males

Samples were collected for the period from October 2023 to March 2024, where the total number of samples reached 384 different samples collected from university buildings. One hundred and ninety-two samples were collected by the open plate method containing the agricultural media (Nutrient Agar, MacConkey Agar, Sabouraud Dextrose Agar, Potato Dextrose Agar) and exposing them to the air in isolation from sunlight for 60 min, and 192 samples were swabbed from hard surfaces such as floors, windows, and furniture. Thus, the total count was specified as 384 (192 by open plates and 192 swabs).

2.2 Total Count and Diversity of Microorganisms

The open plate method and swab method were used to collect air samples. Standard Petri dishes containing Sabouraud Dextrose Agar (SDA) supplemented with 10µg/mL amoxicillin were used for fungal samples, while bacterial isolates were obtained using nutrient agar and MacConkey agar as growth media. All plates were exposed for 60 minutes to indoor air at a height of 150 cm above ground level. The exposed plates were transported to the laboratory in a cool, clean container on the same day. The fungal samples were incubated at 28°C for 7-10 days, and the resulting colonies were identified based on morphological characteristics (shape, size, color, elevation, and edge shape). Additionally, a microscopic examination at 40X was conducted to identify their reproductive structures, including conidia shape, size, arrangement, and mycelium segmentation.

The plates prepared for bacterial isolation were incubated at 37°C for 24 hours, after which the Gram staining technique was employed to analyze the dye pattern, cell morphology, and bacterial aggregations. Biochemical assays (Coagulase Test, Mannitol Salt Agar (MSA), Sugar (e.g., glucose) broth with Durham tubes, Catalase Test, Oxidase Test, Motility Test).

2.3 Air Pollutant Concentrations

Air detectors from the environment lab at Al-Karkh University of Science were used to measure the concentration and distribution of pollutants within different locations of five buildings (building the College of Science and college of energy and environmental sciences, Directorate of Internal Departments, building of student activities, internal departments for females, internal departments for males), (smart sensor, AS8900 multigas detector, China) was used to measure (O₂, H₂S, CO, combustible gas), as well as (protmax, PT6708, China) was used to measure noise.

The readings were recorded in the moderate (October, November), cold (January), and warm (March) seasons from October 2023 to March 2024 using a short measuring technique (15 min/reading).

2.4 Statistical Analysis:

The Statistical Package for the Social Sciences (2019) [15] was employed to analyze the influence of various factors on the study parameters. The Least Significant Difference (LSD) test was applied to determine significant differences between means, while the Chi-square (χ^2) test was utilized to assess significant differences between percentages at probability levels of 0.05 and 0.01.

3. RESULTS AND DISCUSSION

3.1 Characterization of the Sample Population

Air samples were collected using the passive and swab method in the buildings of Al-Karkh University of Science (building the College of Science and college of energy and environmental sciences, Directorate of Internal Departments, building of student activities, internal departments for females, internal departments for males) by depositing microorganisms suspended in the atmosphere on the surface of the culture dish containing the Nutrient Agar, MacConkey Agar for bacteria. After it was opened and left in the air for one hour and by swabbing, it was placed in the incubator for 24 hours at a temperature of 37°. Sabouraud Dextrose Agar and Potato Dextrose Agar for fungi cultivation After it was opened and left in the air for one hour and by swabbing, then it was placed in the incubator for 24 h at a temperature of 37°C. As in (Table 1).

Table 1. Characterization of the Sample Population

Month	Building A (no. of sample)		Building B (no. of sample)		Building C (no. of sample)		Building D (no. of sample)		Building E (no. of sample)		Total
	Swab	Passive	Swab	Passive	Swab	Passive	Swab	Passive	Swab	Passive	
October	16	16	4	4	4	4	12	12	12	12	96
November	16	16	4	4	4	4	12	12	12	12	96
January	16	16	4	4	4	4	12	12	12	12	96
March	16	16	4	4	4	4	12	12	12	12	96
Total	64	64	16	16	16	16	48	48	48	48	384

3.2 Numeration of Bacteria from Air Samples by Nutrient Agar

The results of the average number of colonies of bacteria (nutrient agar media) from air samples collected from different buildings of Al Karkh University are illustrated in (Table 2), represented by the colony-forming unit (CFU). The current results showed that the building the College of Science and the college of energy and environmental sciences were more polluted than other buildings, and this may be because this building has the largest number of students and teachers, meaning it is the most crowded.

Table 2. Average number colonies of bacteria (nutrient agar) from air samples

Month	Building A		Building B		Building C		Building D		Building E	
	Swab CFU\1 mL	Passive CFU\60 min	Swab CFU\1 mL	Passive CFU\60 min	Swab CFU\1 mL	Passive CFU\60 min	Swab CFU\1 mL	Passive CFU\60 min	Swab CFU\1mL	Passive CFU\60 min
October	210 *	103 **	100	25	27	30	35	32	17	7
November	5	95	15	16	12	29	14	111**	9	9
January	164*	123**	185 *	81	75	200 *	17	134**	110**	45
March	26	40	4	24	12	82	12	40	66	43
Total	405	361	304	146	126	341	78	308	202	104

*Unhealthy air quality: **Unhealthy for the sensitive group:

3.3 Numeration of Bacteria from Air Samples by MacConkey Agar

The results of the average number of colonies of bacteria (MacConkey agar media) from air samples collected from different buildings of Al Karkh University are illustrated in (Table 3). The current results show the small number of bacteria isolated on MacConkey agar, which isolated Enterobacteriaceae.

Table 3. Average Number Colonies of Bacteria (Macconkey agar) from Air Samples

Month	Building A		Building B		Building C		Building D		Building E	
	Swab CFU\1mL	Passive CFU\60 min	Swab CFU\1mL	Passive CFU\60 min	Swab CFU\1mL	Passive CFU\60 min	Swab CFU\1mL	Passive CFU\60 min	Swab CFU\1mL	Passive CFU\60 min
October	50	4	.....	.....	.....	.....	.....	.....	.....	.....
November	.....	22	.....	.....	3	.....	.....	9	1	.....
January	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
March	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Total	50	26	.....	.....	3	.....	.....	9	1	.....

3.4 Numeration of Fungi from Air Sample by Sabouraud Dextrose

The results of the average number of colonies of fungi (Sabouraud Dextrose Agar media) from air samples collected from different buildings of Al Karkh University are illustrated in(Table 4).

Table 4. Average number colonies of fungi (Sabouraud Dextrose Agar) from air samples

Month	Building A		Building B		Building C		Building D		Building E	
	Swab CFU\1mL	Passive CFU\60 min	Swab CFU\1mL	Passive CFU\60 min	Swab CFU\1mL	Passive CFU\60 min	Swab CFU\1mL	Passive CFU\60 min	Swab CFU\1mL	Passive CFU\60 min
October	11	7	8	25	2	18	6	4	4	4
November	5	10	7	7	5	5	5	6	4	4
January	64	81	76	30	15	72	15	74	63	53
March	2	8	1	45	3	9	4	12	3	4
Total	82	106	92	107	25	104	30	96	74	65

3.5 Numeration of Fungi from Air Sample by Potato Dextrose Agar

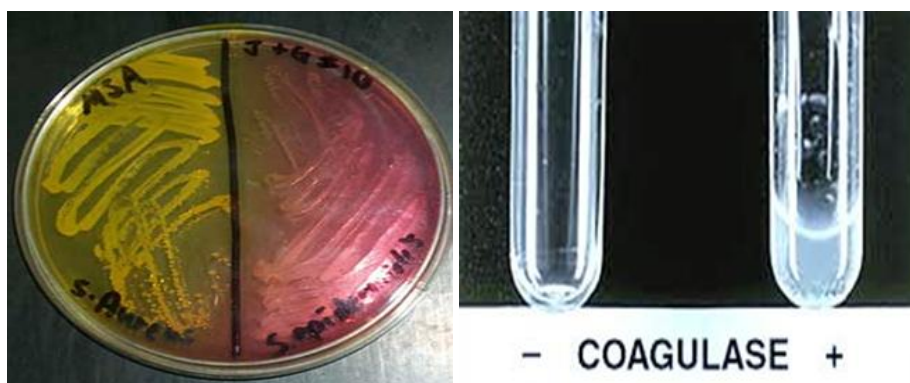
The results of the average number of colonies of fungi (Potato Dextrose agar media) from air samples collected from different buildings of Al Karkh University are illustrated in (Table 5).

Table 5. Average Number Colonies of Fungi (Potato Dextrose Agar) from Air Samples

Month	Building A		Building B		Building C		Building D		Building E	
	Swab CFU\1mL	Passive CFU\60 min	Swab CFU\1mL	Passive CFU\60 min	Swab CFU\1mL	Passive CFU\60 min	Swab CFU\1mL	Passive CFU\60 min	Swab CFU\1mL	Passive CFU\60 min
October	17	6	16	24	10	15	8	7	8	8
November	13	15	.....	2	2	.....	3	5	.....	2
January	64	65	95	73	69	109**	6	78	131**	71
March	17	20	1	30	4	7	5	10	5	3
Total	111	106	112	125	83	131	22	100	144	84

3.6 Identification of Bacteria

The bacterial isolates displayed unique biochemical traits. Under a microscope, *Staph. aureus* was shown to grow in clusters resembling grapes and to be catalase and coagulase positive. At 37 °C, it formed big golden-yellow colonies on nutritional agar. Additionally, the isolates showed that they could ferment mannitol,(Figure 1). Other Gram-positive cocci that were catalase-negative and showed up in chains were identified as *Streptococcus* species.

**Figure 1.** *Staphylococcus* spp. on mannitol agar; coagulase test

Endospore staining showed the presence of *Bacillus* sp. rod-shaped, endospore-forming aerobic or facultatively anaerobic, Gram-positive bacteria. The shape of the colony cultured on ordinary nutrient agar is shown in (Figure 2).

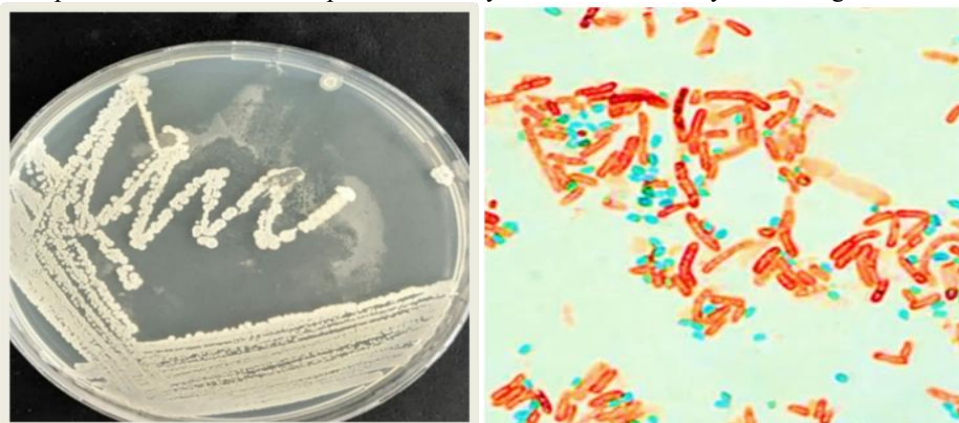


Figure 2. *Bacillus* sp. on nutrient agar; *Bacillus* stained with endospore stain.

Bacterial diversity

Figure (3) shows common bacterial spp. in each month. In October, staphylococci were most isolated (604 CFU/1 mL). In November and January, *Bacillus* was the most isolated (304 CFU/1 mL and 1376 CFU/1 mL). While in March, the most isolated bacteria were Streptococci (575 CFU/1mL).

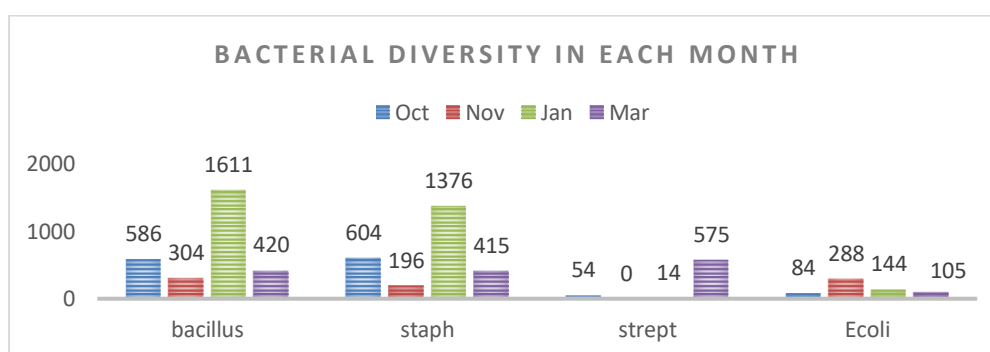


Figure (3): Bacterial Diversity in Each Month

3.7 Identification of Fungi

Fungal isolates were identified by the properties of hyphae, conidia, and spore arrangements. The results of this study showed that most fungi were *Aspergillus niger*, *Trichophyton*, *Penicillium*, *Fusarium*, *Mucor*, *Fonsecaea*, *Curvularia*, *Aspergillus flavus*, *Bipolaris*, and *Cunninghamella*. In moist environments within buildings, mold and bacteria can proliferate rapidly within days and become established as colonies on solid surfaces, subsequently releasing toxins and allergens into the air. The most common indoor molds are *Cladosporium*, *Penicillium*, *Aspergillus*, and *Alternaria*. Molds can cause allergic reactions and chemical toxigenic responses from direct exposure to spores, cell wall components, and mycotoxins. Molds and endotoxins can also be found in tobacco smoke [16,17]. (Figure 4) shows common fungal spp. in each month. In January and March, *Cunninghamella* was most isolated (41 and 26 CFU/1 mL, respectively). In November and October, *Trichophyton* was the most isolated (17 CFU/1mL, and 24 CFU/1mL).

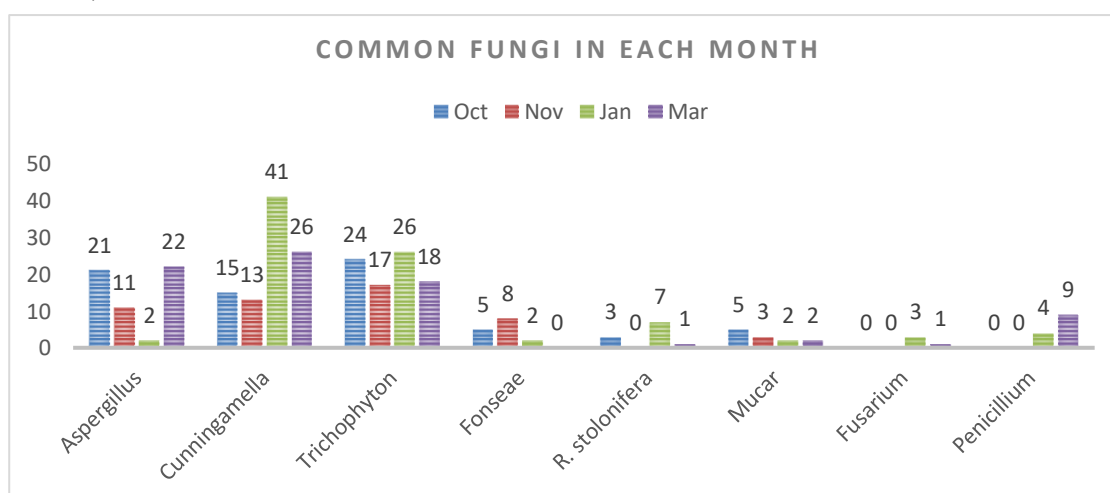


Figure (4): The Most Common Fungi Isolated from Indoors in Each Month

In both environmental engineering and public health protection, the presence of bacteria and fungi in indoor air settings is a significant concern [18]. Since people spend more than 90% of their time in enclosed environments like homes, workplaces, and educational institutions, indoor air quality has become a major public health concern, according to Sadrizadeh et al. [19]. Airborne microorganisms, such as bacteria and fungi, are among the most important sources of indoor air pollution. According to Kubba [20], microbial contamination may cause around one-third of indoor air quality (IAQ) problems, and exposure to such agents can cause immuno-toxic effects, respiratory conditions, and allergic reactions. In general, Air pollution contribute to illnesses and health issues. According to the World Health Organization, air pollution causes around seven million premature deaths each year, and associated illnesses include lung cancer, bronchiolitis, pneumonia, TB, and chronic obstructive pulmonary disease (COPD) [21]. Gram positive counts were found to be greater than Gram negative in the earlier study conducted in India by Karuka and Gaur [22] to quantify the health danger and establish guidelines for indoor air quality.

Using Sabouraud Dextrose Agar (SDA) and Potato Dextrose Agar (PDA) culture mediums, the results in Tables (4) and (5) demonstrated distinct variations in the average fungal colony-forming unit (CFU) counts between the various buildings at Al-Karkh University. Most buildings, especially Buildings A and B, had the highest prices in January, while October and March had a sharp decline in values. The density of airborne fungal spores is directly influenced by seasonal environmental conditions (such as temperature and humidity), with their abundance rising in the colder, more humid months. Some fungal species, including *Aspergillus* and *Penicillium* species, grow better on potato media containing more carbs, as seen by the higher colony-forming unit counts that PDA reported compared to SDA[21]. These outcomes are constant with the results of Gniadek et al. [23] exhibited that the maximum concentrations of aerobic molds in clinics and colleges occur during the colder months due to reduced normal aeration and increased humidity. According to Awad et al. [24], fungal detection varies depending on the type of culture media used, with PDA recording 15–30% higher counts than SDA in comparable environmental samples.

Al-Hamadani & Al-Khafaji [25] also noted that older, poorly ventilated buildings record higher fungal concentrations than newer buildings, which explains the higher CFU in some buildings in the current study compared to others. The discrepancy between swab and passive samples is attributed to differences in the amount of air captured, with passive methods often recording higher counts due to longer exposure times.

The previous research by Shiek et al., [26] study conducted to learn the microbial diversity in the College of Applied Medical Sciences in Saudi Arabia. By the open plate method for 30 minutes, exposed to Nutrient Agar and Sabouraud Dextrose Agar plate, the bacteria isolated were *Staphylococcus aureus*, *Micrococcus*, and *Bacillus*, while the molds isolated were *Aspergillus*, *fumigatus*; *A. niger* ; *Alternaria* and *Penicillium*. The yeast belongs to *Rhodotorula*. The previous research by Sekulska et al. [27] study contamination of indoor air microbiological in various rooms of a university building in Poznan, Poland, by taking an air sample twice a day in the morning and afternoon from various places. Found multiple growth of bacteria and significant increase of mold spores was observed in the afternoons.

The predominant bacteria and molds isolated from the investigated air samples were: *Staphylococcus*, *Alternaria*, and *Aspergillus*, *Rhizopus*. Among these microbes, the presence of pathogenic and strongly allergenic microorganisms was detected. The previous research by Mutib et al., [28] study to evaluate the degree of contamination in surgical and obstetrics theaters in Iraq using the method of taking swabs in many places and identifying and diagnosing pathogenic bacteria isolated from the air and surface swabs. Found types of bacteria that cause severe diseases and allergies are *Staphylococcus aureus*, *Escherichia coli*, *Proteus* spp., *Serratia* spp., *Pseudomonas* spp., *Klebsiella* sp., *Enterococcus* spp., *Haemophilus influenzae*, and *Enterobacter* spp.

Strong Gram-positive bacteria, including *Bacillus*, *Staphylococcus*, and *Streptococcus*, typically predominate in indoor air throughout the year. Because of their increased resilience to environmental stress, these bacteria can remain prevalent all year round. On the other hand, *Aspergillus* and *Penicillium* are more susceptible to variations in temperature and moisture, leading to more noticeable seasonal variations. Studies using both culture-based and molecular methods have demonstrated that while some phyla are relatively stable, the microbial community structure can still shift in response to seasonal environmental factors[29]. Obaid [30] showed in their study conducted in Al-Nu'man Teaching Hospital (Baghdad), 66.7% of air samples were contaminated with fungi, dominated by *Penicillium* spp. and *Aspergillus niger*. The study of Al-Fattly [31] in Al-Diwaniyah slaughterhouses revealed that they contained significant airborne pathogens: *Staphylococcus aureus*, *E. coli*, *Klebsiella pneumoniae*, along with fungi like *Aspergillus flavus/niger* and *Penicillium notatum*.

3.8. Noise Pollution

The results of this study showed that the indoor noise level exceeded the WHO guidelines in some buildings in different seasons. In October, A3 building had a high level of noise (75 dB), in November, A1 had a high level (67.9 dB), while in January, B building scored (65.3 dB). The march month's scored levels were under WHO guidelines, as shown in (Table 6). Health impacts of excessive exposure to noise include hearing loss, headaches, sleep disturbance, cardiovascular stress, hypertension, stress response, and psychological issues [32].

Table 6: Indoor noise levels exceeding WHO guidelines (45–60 dB)

Buildings	Oct	Nov	Jan	Mar	P-value
A1	67.5	67.9	60.9	57.6	0.039 *
A2	62.1	57.4	50	55.7	0.0085 **
A3	75	58	55.5	56.8	0.0006 **
A4	62.1	60.1	56.2	45.8	0.0001 **
B	43.9	48.2	65.3	34.8	0.0001 **
C	50.6	50.6	58.6	33.4	0.0004 **
D1	59.1	46	72.3	29.1	0.0001 **
D2	42.8	42.2	46.2	35.7	0.0291 *
D3	46.5	42.1	53.3	30.3	0.0083 **
E1	52.7	44.7	46.7	28.3	0.0001 **
E2	59.3	56.8	40.5	34.2	0.0001 **
E3	55.5	55.1	43.2	27.4	0.0001 **
P-value	0.0001 **	0.0001 **	0.0001 **	0.0001 **	---
** (P≤0.01).					

3.9. Gaseous Pollutants

The results of this study showed that the indoor H₂S level has significant differences in the buildings among the different seasons. January showed the highest levels of H₂S, while October showed the lowest, as shown in (Table 7).

Table (7): Indoor H₂S levels (ppm)

Buildings	Oct	Nov	Jan	Mar	P-value
A1	9	9	14	12	0.028 *
A2	9	9	13	12	0.033 *
A3	9	9	14	12	0.028 *
A4	9	8	13	12	0.034 *
B	6	9	13	13	0.0082 *
C	8	8	13	11	0.029 *
D1	7	10	13	11	0.0087 **
D2	7	10	12	11	0.0081 **
D3	7	10	12	12	0.0085 **
E1	8	10	13	12	0.029 *
E2	8	10	12	12	0.033 *
E3	8	9	12	12	0.048 *
P-value	0.361 NS	0.377 NS	0.408 NS	0.451 NS	---

* (P≤0.05), ** (P≤0.01).

The results of this study showed that the indoor CO level has significant differences in the buildings among the different seasons. January showed the highest levels of CO, while October showed the lowest, as shown in (Table 8).

Table 8: Indoor CO levels (ppm)

buildings	Oct	Nov	Jan	Mar	P-value
A1	12	14	18	15	0.026 *
A2	12	14	17	15	0.024 *
A3	12	14	17	15	0.024 *
A4	12	13	17	15	0.025 *
B	12	15	18	14	0.026 *
C	14	14	17	15	0.067 NS
D1	13	15	18	15	0.066 NS
D2	13	15	17	15	0.049 *
D3	13	15	17	15	0.049 *
E1	14	15	16	15	0.081 NS
E2	14	15	16	15	0.081 NS
E3	14	15	16	15	0.081 NS
P-value	0.531 NS	0.344 NS	0.302 NS	0.914 NS	---
* (P≤0.05).					

3.10 O₂ depletion

The results of (Table 9) showed a significant decrease in oxygen levels inside buildings (A1–E3) across the study months (October–March), with depletion rates ranging from 0.1 to 1.5% of oxygen compared to the acceptable levels according to OSHA standards (19.5%–23.5%). These values indicate a clear oxygen-deficient condition within most buildings, particularly during October and March, when the lowest values were recorded (0.1–0.8%). Statistically, the results, with a P-value < 0.01, showed highly significant differences ($p \leq 0.01$) between buildings during the study period. This indicates that the decrease in oxygen concentration is linked to various environmental or structural factors within these buildings, such as poor ventilation, accumulation of gaseous pollutants, or high industrial and human activity. November and January showed non-significant values (NS), indicating relative stability in oxygen levels during cold winter periods, which could be attributed to lower temperatures and lower rates of microbial decomposition or internal biological activity.

Table (9): Indoor O₂ depletion Levels

Buildings	Oct	Nov	Jan	Mar	P-value
A1	0.9	1.5	1.5	0.8	0.0063 **
A2	0.9	1.5	1.5	0.8	0.0063 **
A3	0.9	1.5	1.5	0.8	0.0063 **
A4	0.9	1.5	1.5	0.8	0.0063 **
B	0.1	1.5	1.5	0.8	0.0002 **
C	0.9	1.5	1.5	0.8	0.0063 **
D1	0.6	1.5	1.5	0.8	0.0077 **
D2	0.6	1.5	1.5	0.8	0.0077 **
D3	0.6	1.5	1.5	0.8	0.0077 **
E1	0.9	1.5	1.5	0.8	0.0063 **
E2	0.9	1.5	1.5	0.8	0.0063 **
E3	0.9	1.5	1.5	0.9	0.0063 **
P-value	0.0003 **	1.00 NS	1.00 NS	0.806 NS	

Acceptable (OSHA): 19.5%–23.5%. O₂ % Oxygen deficiency: below 19.5%. Oxygen-enriched: Above 23.5% Combustible gas leaks (methane, LPG) pose toxic and explosion hazards. (Table 10) shows that the percentages of flammable gases (such as methane and liquefied petroleum gas (LPG)) inside the studied buildings ranged between 11% and 25% during the various months (October–March). The highest values were recorded in January, reaching 25% in some buildings (A2, A3), while the percentages decreased significantly in March, reaching 7–8% in almost all buildings. P values ≤ 0.01 indicate highly significant differences in gas concentrations between months, indicating that climate changes and variations in ventilation rates have a clear impact on the accumulation of flammable gases inside buildings. The increase in the winter months is attributed to poor ventilation and the use of gas-fired heating systems, which lead to increased methane and LPG emissions inside enclosed spaces. The decrease in March is due to improved natural ventilation conditions with higher temperatures.

Table (10): Flammable gas leaks

Buildings	Oct	Nov	Jan	Mar	P-value
A1	14	14	23	8	0.0016 **
A2	14	15	25	7	0.0017 **
A3	14	14	24	8	0.0017 **
A4	14	13	23	8	0.0016 **
B	11	16	24	7	0.0009 *
C	15	14	21	8	0.0013 **
D1	14	19	23	8	0.0020 **
D2	14	17	22	8	0.0013 **
D3	14	16	22	7	0.0020 **
E1	12	17	21	7	0.0020 **
E2	12	16	20	7	0.0023 **
E3	12	16	20	7	0.0023 **
P-value	0.259 NS	0.0378 *	0.0417 *	0.903 NS	---

* ($P \leq 0.05$), ** ($P \leq 0.01$)

Carbon monoxide (CO) is an odorless toxic gas resulting from incomplete combustion of fossil fuels and is related to the increased risk of heart disease in all ages, increasing by 3.68% and 2.3% when the emission increases by 1 ppm in 1-hour maximum and 8-hour maximum CO, respectively. There is a strong association between CO and NO₂ pollutants. It seems both of them have significant roles in increasing respiratory infection in 0–14 years old and cardiovascular disease in elderly because CO can be attached with hemoglobin molecules and reduce its efficiency in the transport of oxygen [33]. These results are consistent with those of Al-Shammari *et al.* [34], who found that enclosed industrial buildings in urban Iraq suffer from indoor oxygen deficiency due to poor ventilation and the accumulation of gases resulting from fuel combustion and smoking. A study by Lee *et al.* [35] in South Korea also confirmed that poorly ventilated buildings experience a 1–2% decrease in oxygen concentration during the winter months due to closed windows and reduced air exchange.

Bhangar *et al.* [36] showed that indoor oxygen levels are negatively affected by high levels of carbon dioxide (CO₂) and volatile organic compounds, especially in densely populated buildings. Research by the EPA (Environmental Protection Agency)[37] also indicated that an indoor oxygen deficiency of less than 19.5% is an indicator of an unhealthy environment that impacts individuals' physiological performance and may cause headaches, lethargy, and impaired concentration over the long term. The recorded concentrations are a serious indicator of the risks of poisoning and explosion within poorly ventilated buildings. Studies indicate that methane concentrations exceeding 5% by volume are considered to be within the Lower Explosive Limit (LE), making the indoor environment vulnerable to ignition and explosion if a spark is present [38]. These results are in line with those of Li *et al.* [39] and Abdel-Salam *et al.* [40], who verified that closed kitchens and poorly ventilated buildings had higher concentrations of combustible gases, particularly during the winter. Al-Khazraji *et al.* [41] further showed that homeowners' reliance on conventional heating methods and insufficient ventilation systems are strongly associated with the buildup of LPG in Iraqi houses during the cold season. However, research conducted in industrial settings [42] has demonstrated that high methane levels are also linked to distribution pipe breaks and inadequate routine maintenance of gas networks, both of which are prevalent issues in older buildings.

4. CONCLUSION

Numerous overlapping sources of pollution, such as noise, burning gasses, and bioaerosols, are present in indoor spaces across Iraq, posing a serious threat to human health. In addition to the predominance of bacteria and fungi bioaerosols, measured exceedances of WHO and EPA CO and noise thresholds call for immediate reduction. To protect human health, coordinated structural, regulatory, and behavioral actions will be essential. Installing sound insulation, enforcing generator and traffic noise regulations, and mandating ear protection in noisy locations are all recommendations made by Noise Control. Combustion safety: Increase stove ventilation and upgrade generator installations with CO monitors and exhaust systems. Gas leak prevention: Use leak detectors and monitor LPG/methane systems regularly. Reduce bioaerosols by dehumidifying interior areas, maintaining HVAC systems on a regular basis, cleaning wet surfaces, and monitoring the quality of air in medical facilities. Policy & Education: Educate the public, update Iraqi environmental laws, and provide IAQ management training to experts.

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