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Indoor environmental conditions of selected shopping malls in Nigeria: A comparative study of microclimatic conditions, noise levels, and microbial burdens

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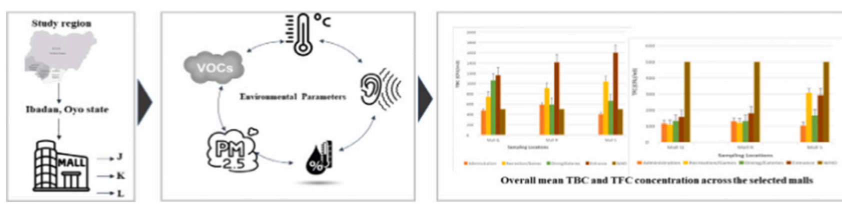
HIGHLIGHTS

- Air pollution and noise levels in malls threaten operator well-being.
- Human-associated bacteria detected, highlighting indoor pollution sources in malls.
- High $PM_{2.5}$ and TVOC concentrations in malls raise concerns for public health.
- High microbial presence in malls demand urgent action for improved air quality.
- Mall operators must prioritize indoor air quality to ensure customer well-being.

GRAPHICAL ABSTRACT



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ABSTRACT

The activities of people and equipment used within shopping malls are major factors that contribute to air pollution and increased sound levels, thereby affecting indoor environmental quality and the well-being of mall operators. This study assessed indoor environmental quality through microbial characterization and measurement of environmental conditions present in selected shopping malls. Investigations were conducted at three shopping malls in Ibadan selected through convenience sampling technique. Environmental parameters such as noise level, relative humidity, temperature, $PM_{2.5}$ levels, total volatile organic compound (TVOC) levels, microbial characterization, and quantity were determined. Microclimatic parameters (temperature and relative humidity) were measured using a 4-in-1 Precision Gold N09AQ multi-tester. Culturable airborne microbes were collected using the settle plate technique. $PM_{2.5}$ and TVOC levels were measured using a Thermo Scientific MIE pDR-1500 PM monitor and sf200-TVOC meter respectively. Two bacteria species and five fungi species were isolated across the malls. The noise levels ranged from 61.27 to 81.20 dB. The mean temperatures (highest mean of 33.44 ± 1.42 °C), $PM_{2.5}$ (highest mean of 114.06 ± 25.64 μg/m^3), and TVOC (highest mean of 55.21 ± 8.28 ppm) concentrations were higher than the permissible limits stipulated by the WHO guidelines and NESREA standard limits across all the selected malls. A positive correlation was found to exist between particulate matter and TVOC ($r = 0.174$, $p = 0.004$). The total bacteria count was generally high with the highest mean of 1965.33 ± 368.56 CFU/m^3, while the total fungi count was generally low with the highest mean of 579.82 ± 51.55 CFU/m^3. *Bacillus* spp. and *Candida* spp. were found to the consistent from all sample points across the three malls. The

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bacteria isolated are Gram-positive bacteria associated with human skin which suggests a high rate of indoor pollution from humans. In conclusion, this research has demonstrated the necessity to monitor noise levels and indoor air quality in malls. Also, there is need for government policies to improve indoor air quality which must be enforced and regulated, especially within shopping malls.

1. Introduction

Approximately 91 % of the world's population lives in places where air quality exceeds the World Health Organization guideline limits (WHO, 2019). Air pollution, a major environmental problem, has affected people's quality of life by creating worse problems for people with health issues and in some cases, some even die of air pollution (Manisalidis et al., 2020; Amodio et al., 2014a; WHO, 2019). It equally has a detrimental impact on flora, fauna and other resources (Manisalidis et al., 2020; NESREA, 2021). One of the problems with indoor air quality is the presence of microorganisms, such as bacteria, molds, and viruses (WHO, 2009). These microorganisms can pose a public health risk, as people spend 80–90 % of their time indoors, including in shopping malls (Wamedo et al., 2012; Moldoveanu, 2015; Shan et al., 2019).

The activity of people and equipment within indoor environments, such as shopping malls, is thought to be the principal factor contributing to the build-up and spread of airborne microbial contamination (Kumar et al., 2021; Bronchu et al., 2006; Lee and Chang, 2000; Tringe et al., 2008; Ashmore and Dimitroulopoulou, 2009; Wichmann et al., 2010). Contaminant agents, whether volatile or in suspension, enter into direct contact with the occupants through their skin, eyes, nose and lung mucosae (Samet et al., 2000). Sealed buildings with heating, ventilation, and air conditioning (HVAC) systems usually present high pollution levels due to low internal/external air exchange rates (Rios et al., 2009). Factors associated with the perceived indoor air quality (IAQ) are not fully understood, but they include temperature, humidity, odours, particulate matter, bioaerosol and volatile organic compound (VOC) contamination (Wolkoff, 2006).

Nigeria, a country with diverse cultures, started witnessing entry and exponential expansion of shopping malls a decade ago (Idoko et al., 2019). Despite this obvious, unprecedented growth and transformation in the retailing domain, which has dramatically re-defined shopping concepts across socio-demographics, there needs to be more understanding about the activities within the emerging segment (Idoko et al., 2019). Shopping malls' climatically controlled, clean, and comfortable interior environment is often preferred over outdoor areas. Even if shopping malls are profit-oriented private properties, people can spend a whole day in them without actually shopping (Amodio et al., 2014b). Therefore, these environments can be considered a new type of public space used for various activities such as shopping, strolling and meeting people in different hours and days of the week (Bruno et al., 2008).

Noise, which is an environmental issue worldwide has become a public health issue, especially in urbanised areas (Kpang and Dollah, 2021). This is due to industrialization, technological, and construction activities, which are mostly outdoors, as well as indoor activities like domestic activities and commercial enterprise, which includes shopping malls (Ibekwe et al., 2016; Kpang and Dollah, 2021; Usikalu and Kolawole, 2018). Due to the multifunctional purpose of shopping malls, several factors responsible for increased noise levels include; a high influx of people, leading to a high rate of traffic and increased tones (Alnuman and Altaweel, 2020), logistic activities, the loading and unloading of products and materials, dropping of empty packages or hitting platforms (Deaconu et al., 2020). Noise pollution is a common source of pollution in metropolitan cities. Asides from air and water pollution, it has been ranked as the third most harmful form of pollution (Ibekwe et al., 2016). Previous studies have shown various health impacts of increased sound levels ranging from irritability, annoyance, headaches, interference with speech communication and in extreme cases hearing loss (Oloruntoba et al., 2012).

Despite these effects, there is a dearth of information on increased sound levels in shopping malls in Nigeria as well as the air quality in these environments and their effects. This study measured indoor environmental quality through microbial characterization and measurement of environmental parameters present in shopping malls in Ibadan. The outcome of this study provides information on current conditions in the shopping malls in Nigeria showing the need for a huge improvement in the mall conditions to support positive indoor air quality. This information will be a useful tool in reviewing existing policies.

2. Materials and methods

2.1. Study area

The study was carried out in three shopping malls which were selected through a convenience sampling technique. However, Ibadan, where the study was conducted, is the capital of Oyo state, Nigeria. The city covers a total area of 3080 km^2. The mean total rainfall is 1420.06 mm, falling in approximately 109 days with two peaks for rainfall, June and September. However, the mean maximum temperature is 26.46 °C with a minimum temperature of 21.42 °C and a relative humidity is 74.55 % (Oladele and Oladimeji, 2011).

2.2. Study location

The selected study malls were labelled Malls Q, R and S. A general description of the selected malls is their proximity to the high ways and presence of possible factors that may predispose them to air and noise pollution. It was observed that all the selected malls had functioning air conditioning system installed and made use of repellents and air fresheners. Key characteristics (geographical point, number of stores in each mall, average number of daily customers and number of workers) of the 3 selected malls are shown in Table 1.

2.3. Sampling points and sampling time

Sampling were carried out across five selected points; administrative section, recreation/game area, eateries/dining area, entrance, and outdoor area of the selected malls. Also, the sampling time were between 8 AM and 11 AM in the morning for off-peak monitoring and 4 PM to 7 PM in the evenings for peak monitoring (Hu and Li, 2015; Moldoveanu, 2015; Shang et al., 2016). The study was conducted between November

Table 1
Key characteristics of the three selected malls.

	Mall Q	Mall R	Mall S
Geographical point of view	It is located 172 m above sea level and 10 m from major road and highway.	It is located 199 m above sea level and 5 m from major road and highway.	It is located 210 m above sea level and 5 m from major road and highway.
Number of stores in each mall	63 stores	48 stores	34 stores
Average number of customers daily	2450 persons	1700 persons	1500 persons
Number of workers	235 persons	157 persons	78 persons

and December, 2020.

2.4. Sampling procedure

Total bacterial and fungal counts were made by passive air sampling technique. A total of 180 settle plates, each with a diameter of 8.5 cm, in two different media (i.e. 90 Sabouraud Dextrose agar (SDA) plates for fungi and 90 Nutrient Agar) were used to collected from 5 selected points in the 3 selected malls; each sampling was done in duplicates twice daily which were during the off peak periods (8 am–11 am) and peak periods (4 pm–7 pm) in all 5 selected sampling points. For the determination of noise, temperature and relative humidity, each of the measurements were done in triplicates in all the 5 selected points using the 4-in-1 Precision Gold N09AQ Environment Meter while for the determination of Particulate matter ($PM_{2.5}$) and total volatile organic compounds (TVOC) were also measured in triplicates using the Thermo Scientific MIE pDR-1500 particulate matter Monitor and sf2000-TVOC meter respectively. The average of the triplicates were calculated and reported for further analyses. All readings and samplings were taken during the off peak periods and peak periods in each mall.

2.5. Determination of microclimatic conditions

Temperature and relative humility were also measured and recorded with aid of a multi-tester, 4-in-1 Precision Gold N09AQ Environmental Meter to measure temperature and relative humidity of selected points within the shopping malls. The values obtained were compared with the World Health Organization guidelines and National Environmental Standards and Regulation Enforcement Agency (NESREA) standard limits (WHO, 2009; NESREA, 2021).

2.6. Determination of microbial load

Culturable airborne microorganisms in air samples were collected using a settle plate technique for a sampling duration of 30 min. The microbial agents were obtained by exposing the petri plates containing Nutrient and Saboraud Dextrose agar at the selected locations for a period of 30 min on platforms between 1 m and 1.5 m high in five strategic locations in the shopping malls which has been approximated to be the human breathing zone and about 0.5 m away from air conditioning system vents (Hu et al., 2015; Shang et al., 2016). The incubation period and temperature conditions for bacteria and fungi were 2 days at 37°C and 4 days at 25°C respectively. The total number of aerobic bacteria and fungi in the selected shopping malls was determined according to Polish Standard PN 89/Z-04008/08. The total number of colony forming units (CFU) per plate was converted to colony forming units per cubic metre (CFU/m^3) according to Omeliansky formula.

$$N = 5a*10^4\ (bt)^{-1}$$

where **N** is the colony forming unit per cubic meter of air, **a** is the number colonies per petri dish, **b** is the surface area of petri dish in cm^2 and **t** is the exposure time (Hayleeyesus and Manaye, 2014).

Bacterial identification was based primarily on morphology, Gram staining, growth characteristic, culture characteristics and biochemical tests. Some commonly found bacteria were identified to the genus level by comparing with standard method. Light microscope was used to determine the colony features and the morphological structures of the fungi. The fungal and bacterial growth on media are shown in Fig. 1. During the colony enumeration, fungal colonies found on settle plates for bacterial colonies were excluded for precision and to avoid counting errors. In other words, the two media, SDA and Nutrient Agar, were specifically used for fungal colonies and bacterial colonies respectively.

2.7. Environmental parameters

$PM_{2.5}$ levels and TVOC levels were monitored using a Thermo Scientific MIE pDR-1500 Particulate Matter Monitor and sf2000-TVOC meter respectively at the sampling points and time accordingly. The devices were switched on and then calibrated. It was placed on a stable platform in order to ensure accuracy of measurement. The measurements were displayed on the display screen and were recorded.

2.8. Data management and statistical analysis

Data obtained were analyzed using Statistical Package for Social Sciences (SPSS Version 20). Descriptive statistics were reported as frequency, mean, standard deviation presented tables and charts. For inferential statistics, independent sample *t*-test was used to compare differences in mean values among selected parameters such as particulate matter concentrations, total volatile organic compounds' concentrations, temperature, relative humidity and microbial burden across the shopping malls and points. Spearman correlation analysis was used to determine associations that exist among indoor air parameters. Tests were considered to be statistically significant at 95 % confidence interval ($p < 0.05$).

2.9. Ethical approval

Ethical approval was obtained from the UCI/UCH Institutional Review Board at the University College Hospital, Ibadan with the assigned

(A) Bacterial growth on media

(B) Fungal growth on media

Fig. 1. Bacterial and fungal growth on media.

UI/UCH Ethics Committee number, UI/EC/19/0142. Also, permissions to carry out the study were obtained from the managers of the malls.

3. Results

3.1. Temperature, relative humidity conditions and noise levels

As shown in Fig. 2, all temperature readings across the selected malls and sampling points exceeded the WHO guideline (25 °C) and NESREA (25.5 °C) standard limit. On the other hand, the relative humidity readings within the permissible limit as recommended by WHO guideline (70 %). The summary of the variations in the indoor noise levels in the shopping malls is depicted on Table 2.

Table 2
Mean noise levels (dB) across sampling periods.

Sampling locations	Sampling points ($n = 3$)	Mean ± SD (dB)		*p*-Value
		Off-peak	Peak	
Mall Q	Outdoor	62.82 ± 4.81	61.27 ± 2.31	0.39
	Administration	72.34 ± 2.89	74.89 ± 1.55	0.03*
	Recreational/game	78.63 ± 3.04	81.04 ± 0.97	0.04*
	Dining/eateries	75.36 ± 5.54	76.53 ± 2.75	0.58
	Entrance	78.17 ± 2.83	77.94 ± 1.83	0.85
Mall R	Outdoor	65.52 ± 6.56	68.48 ± 5.01	0.30
	Administration	72.07 ± 7.41	76.68 ± 1.69	0.09
	Recreational/game	72.49 ± 8.87	81.20 ± 2.64	0.01*
	Dining/eateries	70.67 ± 6.63	77.69 ± 2.48	0.01*
	Entrance	72.31 ± 4.11	79.83 ± 7.16	0.02*
Mall S	Outdoor	63.43 ± 3.02	60.50 ± 4.26	0.11
	Administration	65.53 ± 4.31	70.06 ± 3.36	0.03*
	Recreational/game	74.94 ± 4.53	75.50 ± 4.51	0.80
	Dining/eateries	66.83 ± 2.43	73.03 ± 4.25	0.00*
	Entrance	69.91 ± 2.77	76.19 ± 4.01	0.00*

(Using independent sample *t*-test).
* Depicts that $p < 0.05$.

3.2. Air quality conditions of the selected shopping malls

3.2.1. Particulate matter ($PM_{2.5}$) concentration

Table 3 shows mean and standard deviation of $PM_{2.5}$ levels in malls Q, R, and S. Highest levels observed: Mall Q — entrance (off-peak: 64.73 ± 6.08 μg/m^3, peak: 69.81 ± 8.11 μg/m^3), Mall R — administration section (off-peak: 94.19 ± 14.53 μg/m^3, peak: 114.06 ± 25.64 μg/m^3), Mall S — dining section (off-peak: 81.81 ± 127.98 μg/m^3, peak: 74.21 ± 27.03 μg/m^3). Significant differences: Mall Q — recreational center ($p = 0.02$), Mall R — entrance ($p = 0.02$). All malls exceed WHO guideline for $PM_{2.5}$ level (35 μg/m^3).

3.2.2. Total volatile organic compounds' concentrations

Table 4 shows mean and standard deviation of indoor and outdoor total volatile organic compounds (TVOC) in Malls Q, R, and S. In Mall Q, highest mean off-peak TVOC: Recreational section (54.34 ± 3.14 ppm), peak TVOC: Entrance section (52.03 ± 1.28 ppm). Significant differences in Mall Q: Recreational section ($p = 0.00$) and administration section ($p = 0.00$). Mall R: highest mean off-peak TVOC: Recreational section (55.21 ± 8.28 ppm), peak TVOC: Recreational section (53.38 ± 4.09 ppm). No significant differences in Mall R. Mall S: highest mean off-peak TVOC: Recreational section (55.73 ± 7.60 ppm), peak TVOC: Dining section (52.72 ± 3.40 ppm). Significant difference in Mall S:

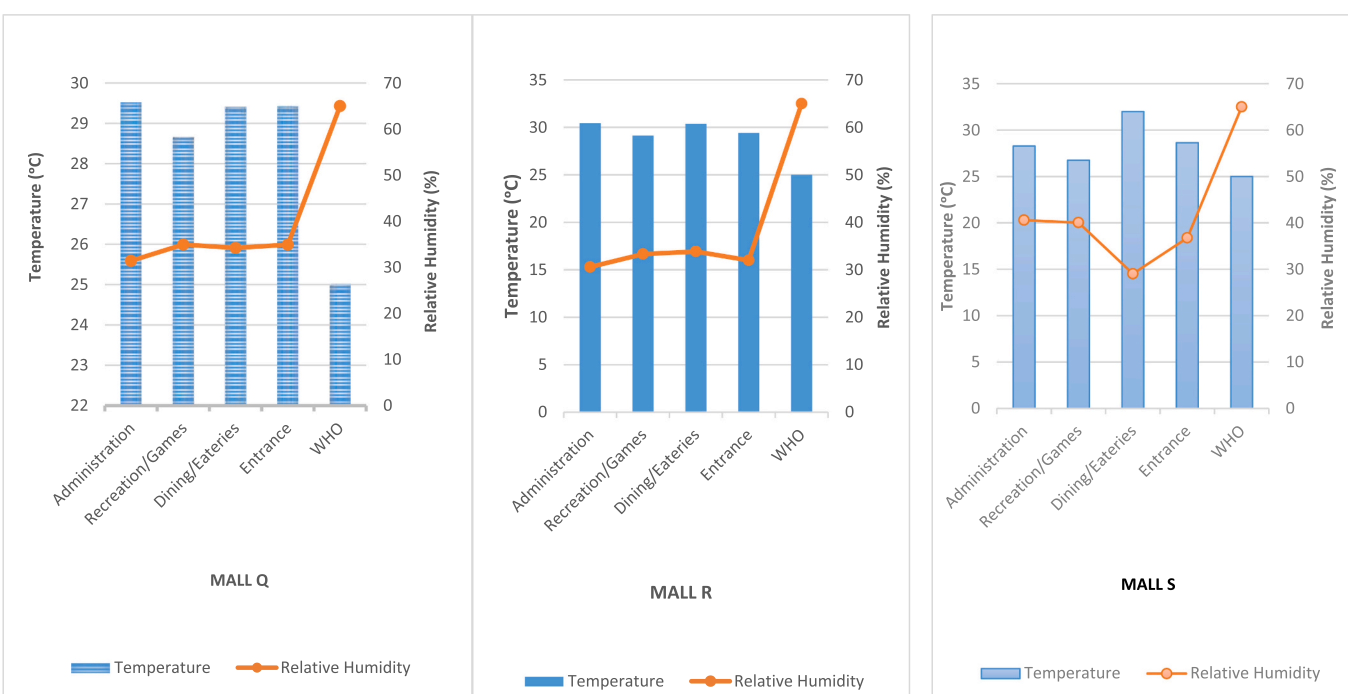

Fig. 2. The mean indoor temperature level (°C) and relative humidity levels (%) across the selected malls.

Table 3
Mean particulate matter levels (μg/m^3) across sampling periods.

Sampling locations	Sampling points (n = 3)	Mean ± SD (μg/m^3)		p-Value
		Off-peak	Peak	
Mall Q	Outdoor	86.36 ± 9.26	69.87 ± 3.12	0.00*
	Administration	44.50 ± 14.51	47.69 ± 11.57	0.61
	Recreational/game	44.09 ± 15.66	66.72 ± 20.08	0.02*
	Dining/eateries	54.36 ± 10.37	49.26 ± 8.04	0.26
	Entrance	64.73 ± 6.08	69.81 ± 8.11	0.15
Mall R	Outdoor	102.98 ± 26.51	100.77 ± 23.82	0.86
	Administration	94.19 ± 14.35	114.06 ± 25.64	0.06
	Recreational/game	79.73 ± 15.50	98.09 ± 23.70	0.70
	Dining/eateries	65.17 ± 11.85	85.61 ± 43.35	0.19
	Entrance	88.96 ± 15.97	99.42 ± 17.97	0.21
Mall S	Outdoor	82.16 ± 20.36	74.01 ± 27.31	0.48
	Administration	43.27 ± 5.12	35.54 ± 11.60	0.09
	Recreational/game	42.70 ± 25.06	36.24 ± 11.55	0.49
	Dining/eateries	81.81 ± 17.98	74.21 ± 27.03	0.49
	Entrance	41.49 ± 6.20	34.03 ± 6.10	0.02*

(Using independent sample *t*-test.)
* Depicts that $p < 0.05$.

Table 4
Mean total volatile organic compounds level (in ppm) across sampling periods.

Sampling locations	Sampling points (n = 3)	Mean ± SD		p-Value
		Off-peak	Peak	
Mall Q	Outdoor	51.53 ± 0.60	51.49 ± 1.42	0.94
	Administration	52.49 ± 0.54	51.19 ± 0.81	0.00*
	Recreational/games	54.34 ± 3.14	50.49 ± 0.17	0.00*
	Dining/eateries	53.41 ± 3.87	50.75 ± 1.04	0.06
	Entrance	53.69 ± 2.73	52.03 ± 1.28	0.12
Mall R	Outdoor	49.85 ± 1.75	52.49 ± 1.96	0.01*
	Administration	50.84 ± 3.58	51.83 ± 1.10	0.44
	Recreational/games	55.21 ± 8.28	53.38 ± 4.09	0.56
	Dining/eateries	51.23 ± 3.49	52.10 ± 1.24	0.49
	Entrance	49.92 ± 1.86	51.23 ± 1.03	0.08
Mall S	Outdoor	56.09 ± 2.50	52.38 ± 1.62	0.00*
	Administration	50.20 ± 0.90	50.47 ± 2.84	0.79
	Recreational/games	55.73 ± 7.60	49.63 ± 1.70	0.03*
	Dining/eateries	52.34 ± 1.32	52.72 ± 3.40	0.76
	Entrance	50.34 ± 1.70	49.91 ± 1.64	0.60

(Using independent sample *t*-test.)
* Depicts that $p < 0.05$.

Recreational section ($p = 0.03$). All malls exceeded WHO standard for TVOC (3 ppm).

3.2.3. Total bacteria count and total fungi count

Fig. 3 displays mean total bacteria count (TBC) and mean total fungi count (TFC) at each sampling location in the malls, compared to WHO standards. TBC ranged from 404.92 to 1598.25 CFU/m^3 across sample locations. In Mall Q, highest TBC at entrance (1160.68 CFU/m^3) and lowest at administration section (475.36 CFU/m^3). In Mall R, highest TBC at entrance (1412.39 CFU/m^3) and lowest at administration and dining sections (589.12 and 589.96 CFU/m^3, respectively). In Mall S, highest TBC at entrance (1598.25 CFU/m^3) and lowest at administration section (404.92 CFU/m^3). Entrance TBC is 3 times higher in all the malls. TBC in all sections exceeds WHO (500 CFU/m^3) and NESREA (500 CFU/m^3) limits, except at the administration section. Fungi concentrations in malls are generally lower than WHO and NESREA standards.

3.3. Risk characterization for environmental pollutants across points

According to WHO and NESREA guidelines (WHO, 2009; NESREA, 2021), parameters in the sampled malls varied in risk levels. In Table 7, Mall Q had high risk for $PM_{2.5}$, TVOC, and temperature. Humidity was moderate at entrance and recreational areas, and low at dining and administration sections. Sound was generally at moderate risk. Total bacteria count was moderate at the entrance but high elsewhere, while Total Fungi Count (TFC) was generally low risk. In Table 8, all malls had high risk for $PM_{2.5}$, TVOC, temperature, and TBC. Sound was at moderate risk, while humidity and TFC were at low risk in all areas. In Table 9, TFC was low risk in all sample areas. Sound was at moderate risk across all points, and humidity was moderate except for low risk in the dining area.

3.4. Indoor and outdoor airborne bacterial and fungal load among selected shopping malls

The highest mean off-peak indoor TBC recorded were 1261.84 ± 704.36 CFU/m^3, 1042.83 ± 541.60 CFU/m^3 and 1231.18 ± 399.86 CFU/m^3 in Mall Q, Mall R and Mall S respectively while the highest mean peak indoor TBC recorded were 1213.05 ± 687.07 CFU/m^3, 1828.14 ± 608.66 CFU/m^3 and 1965.33 ± 368.56 CFU/m^3 in the same order respectively (see Table 5). However, the highest mean off-peak indoor TFC recorded were 175.87 ± 47.11 CFU/m^3, 163.09 ± 48.38 CFU/m^3 and 414.68 ± 73.97 CFU/m^3 in Mall Q, Mall R and Mall S respectively while the highest mean peak indoor TFC recorded were 207.93 ± 36.79 CFU/m^3, 203.27 ± 49.09 CFU/m^3 and 579.82 ± 51.55 CFU/m^3 in the same order respectively (see Table 6).

3.5. Correlation matrix of air quality parameters

Table 10 shows the correlation matrix of indoor air quality parameters in the shopping malls. Negative correlations were found between temperature and relative humidity ($r = -0.510$, $p = 0.000$), and between particulate matter and relative humidity ($r = -0.354$, $p = 0.000$). A positive correlation was observed between particulate matter and TVOC ($r = 0.174$, $p = 0.004$). However, no relationship was found between total bacterial count and total fungal count.

3.6. Isolated airborne microorganisms from the shopping malls

In Table 11, various bacteria and fungi were isolated from different sample areas in the three malls. *Staphylococcus aureus* was present in all areas of all three malls. *Staphylococcus epidermidis* was found in all areas of Mall Q and Mall R, and in selected areas of Mall S. *Bacillus* spp. was isolated from all sample points in all malls. Five fungi species were found across the three malls. *Aspergillus niger* was present in all areas of Mall R

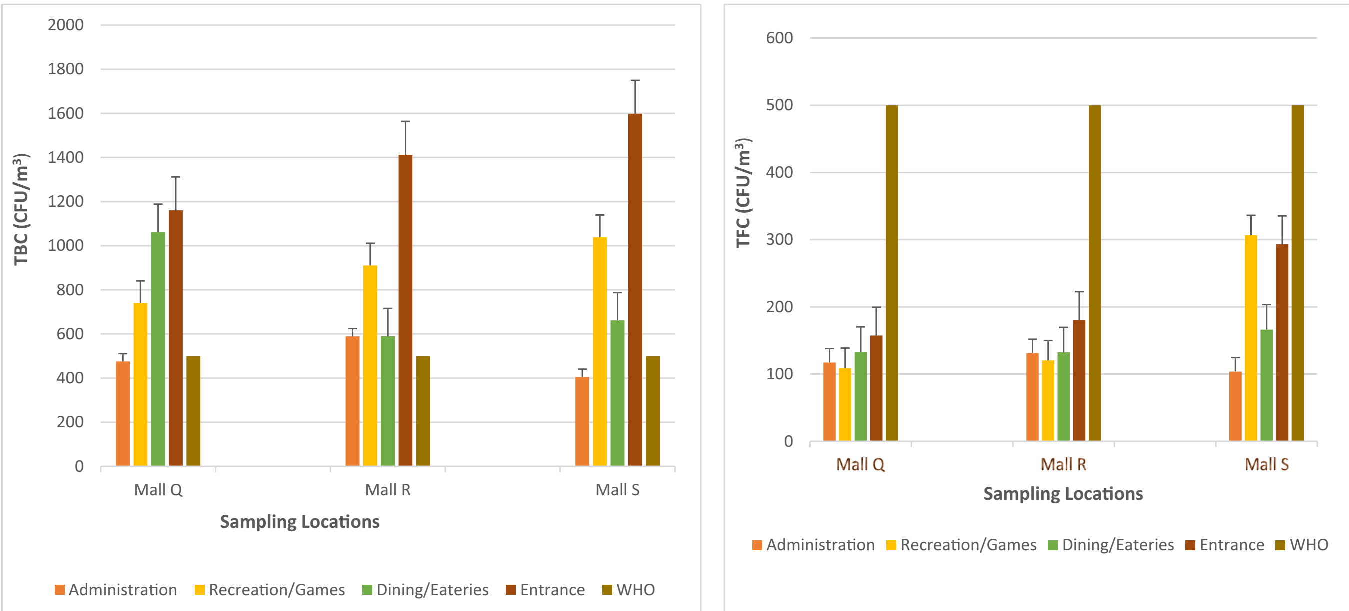

Fig. 3. Overall mean total bacteria count (TBC) and total fungi count (TFC) concentrations across the selected malls.

Table 5
Mean total bacterial counts (in CFU/m^3) across sampling periods.

Sampling locations	Sampling points (n = 3)	Mean ± SD		*p*-Value
		Off-peak	Peak	
Mall Q	Outdoor	1056.82 ± 484.18	1597.28 ± 621.29	0.16*
	Administration	526.69 ± 325.21	429.72 ± 295.45	0.37*
	Recreational/game	810.66 ± 250.60	669.39 ± 257.43	0.36*
	Dining/eateries	911.88 ± 485.69	1213.05 ± 687.07	0.35*
	Entrance	1261.84 ± 704.36	1059.51 ± 376.66	0.53*
Mall R	Outdoor	1495.50 ± 478.17	1262.46 ± 726.62	0.51*
	Administration	431.19 ± 123.14	769.62 ± 418.09	0.07*
	Recreational/game	718.88 ± 383.93	1113.46 ± 585.75	0.10*
	Dining/eateries	448.95 ± 372.43	730.98 ± 432.00	0.04
	Entrance	1042.83 ± 541.60	1828.14 ± 608.66	0.02
Mall S	Outdoor	1171.87 ± 356.47	731.96 ± 542.40	0.08*
	Administration	347.58 ± 203.27	462.25 ± 256.98	0.15*
	Recreational/game	924.38 ± 352.16	1153.10 ± 440.45	0.26*
	Dining/eateries	479.37 ± 120.56	823.76 ± 422.20	0.06*
	Entrance	1231.18 ± 399.86	1965.33 ± 368.56	0.02

(Using independent sample *t*-test.)
* Depicts that $p < 0.05$.

Table 6
Mean total fungal count (in CFU/m^3) across sampling periods.

Sampling locations	Sampling points (n = 3)	Mean ± SD		*p*-Value
		Morning	Evening	
Mall Q	Outdoor	161.47 ± 45.68	171.24 ± 52.99	0.87
	Administration	104.32 ± 51.53	128.65 ± 59.71	0.49
	Recreational/game	86.02 ± 33.50	132.11 ± 49.87	0.30
	Dining/eateries	83.18 ± 59.77	207.93 ± 36.79	0.01*
	Entrance	175.87 ± 47.11	140.91 ± 49.26	0.50
Mall R	Outdoor	209.73 ± 55.38	486.15 ± 60.60	0.07
	Administration	122.92 ± 59.42	140.52 ± 68.65	0.68
	Recreational/game	117.44 ± 38.05	123.70 ± 48.48	0.85
	Dining/eateries	189.97 ± 14.86	180.73 ± 50.46	0.16
	Entrance	163.09 ± 48.38	203.27 ± 49.09	0.61
Mall S	Outdoor	227.53 ± 61.01	106.16 ± 34.67	0.09
	Administration	132.11 ± 79.19	79.69 ± 13.52	0.19
	Recreational/game	414.68 ± 73.97	220.19 ± 54.48	0.09
	Dining/eateries	151.66 ± 47.55	177.24 ± 60.51	0.71
	Entrance	269.09 ± 34.70	579.82 ± 51.55	0.06

(Using independent sample *t*-test.)
* Depicts that $p < 0.05$.

and Mall S, and in selected areas of Mall Q. *Aspergillus penicillin* was only found in the recreational games section of Mall Q and the dining section of Mall S. *Candida* spp. was isolated from all areas in all malls. *Aspergillus flavus* was present in all areas of Mall Q, selected areas of Mall R, and selected areas of Mall S. *Alternaria* spp. was isolated only from the dining and recreational games sections of Mall S.

4. Discussion

From the study, the mean indoor temperatures were high and relative humidity values were generally low across the malls. The mean indoor temperatures were higher than the WHO standard and the NESREA standard of 22.5–25.5 °C and 25.5 °C respectively; these values recorded could easily be a resultant effect of the air conditioning systems

Table 7
Risk characterization for environmental pollutants across points in Mall Q.

Parameters	Range of Values	Degree of Risk	Sampling points			
			Entrance	Administration	Dining	Recreational/Games
$PM_{2.5}$ (μg/m^3)	>25	High				
	13-15	Moderate				
	<13	Low				
TVOC (ppm)	>3	High				
	1-3	Moderate				
	<1	Low				
Temperature (°C)	>25	High				
	13-25	Moderate				
	<13	Low				
Humidity (%)	>65	High				
	33-65	Moderate				
	<33	Low				
Sound (dB)	>90	High				
	45-90	Moderate				
	<45	Low				
TBC (CFU/m^3)	>500	High				
	250-500	Moderate				
	<250	Low				
TFC (CFU/m^3)	>500	High				
	250-500	Moderate				
	<250	Low				

Legend: Red is "above permissible limits", blue is "within permissible range", green is "below permissible limit".

Table 8
Risk characterization for environmental pollutants across points in Mall R.

Parameters	Range of Values	Degree of Risk	Sampling points			
			Entrance	Administration	Dining	Recreational/Games
$PM_{2.5}$ (μg/m^3)	>25	High				
	13-15	Moderate				
	<13	Low				
TVOC (ppm)	>3	High				
	1-3	Moderate				
	<1	Low				
Temperature (°C)	>25	High				
	13-25	Moderate				
	<13	Low				
Humidity (%)	>65	High				
	33-65	Moderate				
	<33	Low				
Sound (dB)	>90	High				
	45-90	Moderate				
	<45	Low				
TBC (CFU/m^3)	>500	High				
	250-500	Moderate				
	<250	Low				
TFC (CFU/m^3)	>500	High				
	250-500	Moderate				
	<250	Low				

Legend: Red is "above permissible limits", blue is "within permissible range", green is "below permissible limit".

and humidifiers used to cool the spaces sampled. High temperatures are known to support the growth of certain microorganisms. This is similar to a study by Shittu et al., 2019, which recorded lower temperatures and relative humidity in indoor locations sampled due to air conditioning systems. Generally, there was no significant difference in the relative humidity measured except in the administration section in Mall R at $p > 0.05$ and the dinning and entrance section in Mall S at $p < 0.05$.

Variations in noise levels across each mall is considerably significant. Across the malls, the highest noise levels were noticed in the entrance section, dining section and recreational areas. All other locations had lower noise levels, and this could be attributed to the high influx into the malls at the entrance section before being dispersed across the malls, noise from the mall surroundings due to its nearness to busy roads (Omeokachie et al., 2023), the large number of people dinning as well as the buzzing happy sounds from the people having fun at the recreational areas. The results also showed that sound levels from these areas were considerably higher in the evenings than mornings similar to the study done by Alnuman and Altaweel (2020) in Jordan. Workers in the mall who are consistently exposed to these noise levels are at high risk. It is important to put into consideration the installation of better acoustic absorbers in hotspot areas of the mall (dining, entrance and recreational area) in order to reduce the effect of increased sound levels (Oluwatayo et al., 2020; Deaconu et al., 2020).

The particulate matter ($PM_{2.5}$) levels recorded across the sections of the three malls all exceeded the WHO guideline of 35 μg/m^3. These high levels recorded are expected due to the various anthropogenic activities, including the use of air fresheners and repellants, activities such as movement of humans across sections which enables the movement of fine particles, cooking activities (Hu and Li, 2015) and even dust from equipment within the shopping mall (Kiresova and Guzan, 2022). The

Table 9
Risk characterization for environmental pollutants for Mall S.

Parameters	Range of Values	Degree of Risk	Sampling points: Entrance	Administration	Dining	Recreational/Games
$PM_{2.5}$ (μg/m^3)	>25	High	Red	Red	Red	Red
	13-15	Moderate				
	<13	Low				
TVOC (ppm)	>3	High	Red	Red	Red	Red
	1-3	Moderate				
	<1	Low				
Temperature (°C)	>25	High	Red	Red	Red	Red
	13-25	Moderate				
	<13	Low				
Humidity (%)	>65	High				
	33-65	Moderate	Blue	Blue		Blue
	<33	Low			Green	
Sound (dB)	>90	High				
	45-90	Moderate	Blue	Blue	Blue	Blue
	<45	Low				
TBC (CFU/m^3)	>500	High	Red	Red	Red	Red
	250-500	Moderate				
	<250	Low				
TFC (CFU/m^3)	>500	High				
	250-500	Moderate				
	<250	Low	Green	Green	Green	Green

Legend: Red is “above permissible limits”, blue is “within permissible range”, green is “below permissible limit”.

Table 10
Correlation matrix of air quality parameters using Spearman correlation analysis.

	Temperature	Relative humidity	$PM_{2.5}$	TVOC	TBC	TFC
Temperature	1					
Relative humidity	**−0.510****	1				
	0.000					
$PM_{2.5}$	**0.308****	**−0.354****	1			
	0.000	**0.000**				
TVOC	0.041	0.059	**0.174****	1		
	0.502	0.335	**0.004**			
TBC	0.005	−0.012	−0.063	0.021	1	
	0.935	0.856	0.318	0.739		
TFC	−0.008	0.103	**−0.173****	−0.099	0.099	1
	0.903	0.127	**0.010**	0.145	0.051	

** $p < 0.05$ (values in boldface are significantly different).

Table 11
Profile of the isolated airborne microbes from the shopping malls.

Type of microorganisms isolated	Mall Q				Mall R				Mall S			
	1	2	3	4	1	2	3	4	1	2	3	4
Bacteria												
Staphylococcus aureus	x	x	x	x	x	x	x	x	x	x	x	x
Staphylococcus epidermidis	x	x	x	x	x	x	x	x	x		x	x
Bacillus spp	x	x	x	x	x	x	x	x	x	x	x	x
Fungi												
Aspergillus niger	x	x		x	x	x	x	x	x	x	x	x
Aspergillus penicillin				x							x	
Aspergillus flavus	x	x	x	x	x			x		x		x
Candida spp	x	x	x	x	x	x	x	x	x	x	x	x
Alternaria sp											x	x

Where 1 is “Entrance section”, 2 is “Administration section”, 3 is “Dining/eatery section”, 4 is “Recreational/games section”.

results obtained here corroborate the results from a study carried out in a commercial study area with $PM_{2.5}$ levels exceeding the set guidelines (Abulude et al., 2022). Mall R and Mall S had significantly higher levels of $PM_{2.5}$ and TVOC respectively at their entrances, and this could be due to their 5 m proximity from major roads and highways which is likely to introduce air pollutants from vehicular emissions, wind-blown dust from the surroundings (Kiresova and Guzan, 2022). The high $PM_{2.5}$ and TVOC concentrations observed in this study can reduce the general indoor environmental quality of the malls. Indoor environmental quality has become a public health concern as a rise in outdoor air pollution levels causes increased toxicity of indoor air quality (Omeokachie et al., 2023). Various studies have documented the effects of $PM_{2.5}$ and TVOCs on human health. Most shoppers in the mall are exposed short-term to these substances, while mall staff who work long hours might experience the effects of long-term exposure, especially those with pre-existing conditions. Cardiovascular diseases and acute nasopharyngitis are found to be related to long-term exposure to $PM_{2.5}$ (Manisalidis et al., 2020).

Bio-aerosols constitute about 50 % of the total atmospheric aerosols (Ana et al., 2015a) and are responsible for 5 %–34 % of indoor air pollution (Stanley et al., 2010). Shopping malls are microbial environments which potentially facilitate the transmission of microorganisms of public health concern to humans and the environment (Ana et al., 2015b). This study shows a presence of microbial contamination of fungi and bacteria in shopping malls. The microbial isolates characterized include 3 bacteria and 5 fungi. The bacterial isolates include *Staphylococcus aureus*, *Staphylococcus epidermidis* and *Bacillus* spp. The identification of bacteria isolates confirmed that they are Gram-positive bacteria. WHO set a guideline for bacterial load not to exceed 500 CFU/m^3. The amount of bacterial load present across the malls exceeded the set guideline and is considered significantly high. The entrance areas were recorded to have the highest bacterial load across the three malls. *Aspergillus* spp. was the most predominant fungi isolated with three variants identified. This is similar to a study carried out on indoor air in Lagos, Nigeria, which identified *Aspergillus* spp. as the most predominant fungi (Shittu et al., 2019). The fungi specie seen to be consistent across the three malls is the *Candida* spp. Generally, the fungi load was reduced across the malls compared to the high bacteria load; this could be attributable to the increased temperature and low humidity situation of the malls. Reduced exposure to these fungi minimises the risk of humans to health conditions such as allergy, rhinitis, asthma and conjunctivitis, and sick building syndromes, which are considered potential causative agents for (Hayleeyesus and Manaye, 2014). The isolated gram-positive bacteria species are mostly associated with the human skin, suggesting that indoor bacterial contamination is gotten from the presence of humans in the mall (Hayleeyesus and Manaye, 2014).

The frequency of people visiting the shopping malls, the amount of time spent while shopping and the conditions around the mall may significantly increase the temperature of the mall. This makes it important to consider the quality of air humans who patronize these malls are exposed to. Across the selected malls in this study, we noticed a negative correlation between temperature and relative humidity. This observation between temperature and relative humidity ($r = -0.510$, $p = 0.000$) would mean that the higher the temperature of the malls, the lower the relative humidity, and this implies that there is reduced chances for particulate matter to be carried around the mall. This observation supports a review by Kiresova and Guzan, 2022 which showed that increased temperature caused a significant reduction in the concentration of particulate matter in the air. Further in this study, we however recorded a significantly high temperature level and a significantly high concentration of $PM_{2.5}$ in the areas sampled. Despite the low relative humidity recorded in this study, the high concentration of $PM_{2.5}$ could be explained to be as a result of the commercial activities ongoing within the mall which includes the use of machines or even cooking activities from eateries within the mall. Outdoor particle pollution is also a likely explanation of the high $PM_{2.5}$ concentrations observed as particles from the outdoor environment may infiltrate the malls through in and out movement of people.

Higher temperature observed within the malls can reduce thermal comfort to the humans in the mall thus creating an unconducive environment both for the shoppers and the mall staffs. Frequent shoppers at the mall and mall staffs may be exposed to multiple health problems resulting from consistent exposure to insufficient thermal conditions.

Temperature is a very important factor for the growth and survival of microorganisms. *Staphylococcus* spp., can survive over a wide temperature range, but they are known to thrive in higher temperatures. This explains its presence in high concentrations across the three malls examined in this study. Improvement of air-cooling systems within shopping malls is important in achieving a positive indoor air quality across these malls.

5. Conclusion

The need to assess environmental conditions cannot be overemphasized as it is tantamount to the health and safety of humans. This study highlights the indoor environmental quality of malls in Ibadan and the need for further attention on safe environmental conditions within shopping malls as it poses health hazards to workers who encounter long-term exposure and, in some cases, shoppers who are exposed for only a short while. The close proximity of the malls to busy roads puts them at risk of infiltration of dust and fumes from vehicular exhaust which ends up introducing unfavourable environmental conditions to the mall and, by extension, to those within. Although it was observed that the malls all had functional air conditioning systems, there was a general increased temperature, which exposes the mall staffs and shoppers to unconducive thermal conditions, it becomes important to ensure that the cooling systems are sufficient for the capacity of the malls. It is recommended that policies that the government puts in place measures to ensure regulated bodies enforce that indoor environmental quality assessment be carried out periodically. Maintenance and cleaning of air conditioning system should be done periodically to ensure that they function properly and clean air is ventilated within the malls.

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CRediT authorship contribution statement

Doris N. Omeokachie: Conceptualization, Methodology, Investigation, Writing – review & editing, Formal analysis, Writing – original draft, Data curation, Project administration. **Temitope A. Laniyan:** Project administration, Methodology. **David B. Olawade:** Methodology, Writing – review & editing, Writing – original draft. **Omotayo Abayomi-Agbaje:** Methodology, Writing – review & editing, Data curation. **Deborah T. Esan:** Methodology, Writing – review & editing, Formal analysis. **Godson R.E.E. Ana:** Methodology, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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