Air Quality Evaluation of Built Workspace Environments and Antibiotic Sensitivity to Its *Staphylococcus* Species

Olusola-Makinde, Olubukola Olayemi (iD)

1. Department of Microbiology, Federal University of Technology, P.M.B. 704, Akure, Nigeria

Abstract: The health and wellness of employees can be significantly impacted by the air quality of designed office spaces. The study assessed the microbial, physical and chemical air quality of built environments in Federal University of Technology Akure, Nigeria and sensitivity of associated *Staphylococcus* species to conventional antibiotics. Air samples were examined for *Staphylococcal* counts using the settle plate technique and characterized by standard microbiological methods for identification. Physicochemical qualities of studied air samples were determined using standard methods. Bacterial isolates were profiled for antibiotic sensitivity using the disc diffusion technique. *Staphylococcal* count ranged from 2.4×10^1 to 6.0×10^1 cfu/m^3 and 3.8×10^1 to 6.5×10^1 cfu/m^3 in air samples of offices with fully air conditioned and offices with open window systems respectively. Presumptive identification confirmed prevalent isolates as *Staphylococcus aureus* and *S. epidermidis*. On average, levels of volatile organic compounds, formaldehyde and particulate matter (PM$_{2.5}$) were higher in air samples of environments with air-conditioned system than environments with open-window system. *S. aureus* was susceptible to ciprofloxacin (10 μg) at 38.66±3.48 mm zone of inhibition. Findings reveal the presence of *Staphylococcus* spp. in air samples of built workspace with poor physicochemical qualities. These indicate need for regular monitoring and sanitization so as to mitigate occupation health risks associated with poor air quality.

Keywords: air quality, antibiotic sensitivity, built workspace, *Staphylococcus* spp., volatile organic compounds, formaldehyde and particulate matter (PM$_{2.5}$ and PM$_{10}$)

INTRODUCTION

Indoor air quality (IAQ) is the air quality within and around buildings and structures. IAQ is known to affect the health, comfort, and well-being of building occupants. Poor indoor air quality has been linked to sick building syndrome, reduced productivity, and impaired learning in schools. IAQ can be affected by gases (including carbon monoxide, radon, volatile organic compounds), particulates, microbial contaminants (mold, bacteria), or any mass or energy stressor that can induce adverse health conditions. Source control, filtration, and the use of ventilation to dilute contaminants are the primary methods for improving indoor air quality in most buildings (EPA, 2022).

Due to the negative effects of indoor air pollution on human health and comfort, indoor air quality has grown in importance. The World Health Organization claims that indoor air pollution is one of the main factors contributing to early deaths globally. It can also lead to respiratory disorders, cardiovascular diseases, and other health issues (WHO, 2018). There are many different sources of indoor air pollution, such as external smog, construction materials, furniture, cleaning supplies, and human activities like cooking and smoking (EPA, 2022).

Indoor air pollution is a major health hazard in developing countries. A major source of indoor air pollution is the burning of coal, and biomass including wood, charcoal, dung, or crop residue for heating and cooking. This results in high concentrations of particulate matter and was responsible for roughly 1.5 million to 2 million deaths in 2000.

Poor indoor air quality has been linked to decreased productivity, impaired cognitive function, and poor health, according to research (ASHRAE, 2019). Because the COVID-19 virus can spread through indoor air, the pandemic has brought attention to the significance of indoor air quality.

Built environment such as offices are one of the most important places in a society. Poor IAQ is often viewed as a problem peculiar to modern buildings, linkages between air quality and disease have been known for centuries. Long before the germ theory of disease led to recognition of pathogenic microorganisms, foul vapours were being linked with infectious diseases. Contaminated indoor air thus has the potential to harm public health. Due to the importance of the air quality in community, this research is aimed at investigating the microbial quality and physicochemical properties in the air. The study determined physical and chemical parameters of air environment of built workspace, the prevalence of *Staphylococcus* spp. was assayed and the isolates' antibiotic sensitivity profile.

MATERIALS AND METHODS

Study Sites

The study sites for this work were offices at the School of Environmental Science (SET) building, Federal University of Technology, Akure. There are two groups; Group A has open window system of aeration and Group B has enclosed system of aeration (with air-conditioned system).

Methods

Physicochemical Analysis of Built Air Samples

Physicochemical parameters of air samples were determined using standard air sampler (air quality monitor) (Olusola-Makinde *et al*., 2022). The parameters were temperature, relative humidity, CO_2, particle matter (PM), volatile organic compounds (VOCs), and carbon dioxide (CO_2)

Microbiological Analysis of Built Air Samples

Isolation of isolates from air samples was carried out using the settle plate method as described by (Olusola-Makinde *et al*., 2022). This is done by exposing a prepared and solidified sterile plates of nutrient agar and mannitol salt agar (MSA) in the preferred environment for 1hour after which the plate was incubated for 24 hours and observed. The plates were exposed weekly for six weeks. After exposure, covered plates were transported to the microbiology laboratory, FUTA within an hour of exposure. The plates were incubated at 37°C for 24 hours. After incubation, colonies were observed and counted appropriately.

Identification of Test Organisms

Colonies were sub cultured on sterile mannitol salt agar (MSA) plates and subjected to preliminary identification using morphological and biochemical characterization such as Gram staining, catalase, coagulase, sugar fermentation and motility tests as described by Olusola-Makinde *et al*. (2024).

Antibiotic Sensitivity Test Using Conventional Antibiotics

Antibiotics sensitivity test was carried out using the method as described by Ojo *et al*. (2024). A multi sensitivity disk bearing multiple antibiotics pefloxacin (PEF) 10µg, gentamycin (CN) 10µg, ampiclox (APX) 30µg, zinnacef (Z) 20µg, amoxacillin (AMX) 30µg, rocephin (R) 25µg, ciprofloxacin (CPX) 10µg, streptomycin (S) 30µg, septrin (SXT) 30µg, erythromycin (E) 10µg were used against each of the *Staphylococcus* spp. isolates inoculated on Mueller Hinton agar plates. They were incubated at 37℃ for 24hours. After incubation, the diameter of the zones of inhibition around each was well measured to the nearest millimeter.

RESULTS

Staphylococcal Counts of Air Samples

Staphylococcal count ranged from 2.4×10^1 to 6.0×10^1 cfu/m^3 and 3.8×10^1 to 6.5×10^1 cfu/m^3 in air samples of offices with fully air conditioned and offices with open window systems respectively. The total *Staphylococcal* count (CFU/m^3) of studied air samples were represented in Table 1.

Identification of *Staphylococcal* Isolates

Presumptive identification confirmed prevalent isolates as *Staphylococcus aureus* and *S. epidermidis*. *Staphylococcus aureus* isolates were positive to Gram staining, catalase, and coagulase test. *Staphylococcus epidermidis* were also positive to Gram staining, Catalase test and negative to coagulase test. Table 2 showed morphological and biochemical characteristics of bacterial isolates. *Staphylococcus aureus* (A) and *Staphylococcus epidermidis* (B) pictorial growth on nutrient agar plates was presented in Plate 1.

Physicochemical Characterization of Built Air Samples

Figures 1 to 6 represented the physicochemical parameters of studied air samples. On average, levels of volatile organic compounds, formaldehyde and particulate matter (PM$_{2.5}$) were higher in air samples of offices with fully air conditioned and offices with open window systems.

Antibiotic Sensitivity of *Staphylococcus aureus* Isolated from Air Samples

Staphylococcus aureus was susceptible to majority of the tested conventional antibiotics. The antibiotic test result using conventional antibiotics showed ciprofloxacin and

streptomycin as the most potent antibiotics with the highest zones of inhibition. While antibiotics like zinnecef (20µg), rocephin (25µg), septrin (30µg), amoxicillin (30µg), and ampiclox (30µg) were the least effective with little zone of inhibition due to bacteria resistance as shown on Table 4.

Table 1: Total *Staphylococcal* count (CFU/m^3) of air samples

Sites		Total bacterial counts (CFU/m^3)
Week 1: Group A		4.1×10^1
	Group B	5.2×10^1
Week 2: Group A		5.7×10^1
	Group B	6.1×10^1
Week 3: Group A		2.4×10^1
	Group B	5.3×10^1
Week 4: Group A		3.1×10^1
	Group B	4.3×10^1
Week 5: Group A		3.4×10^1
	Group B	3.8×10^1
Week 6: Group A		6.0×10^1
	Group B	6.5×10^1

Key: Group A = Office with air-conditioned system; Group B = Office with window system

Table 2: Morphological and biochemical characteristics of bacterial isolates

	Colony morphology	Gram reaction	Shape	Catalase	Coagulase	Glucose	Motility	Probable organism
Week 1 Group A	Circular, yellow colony, convex, entire	+	Cocci	+	+	+	-	*Staphylococus aureus*
Week 1 Group B	Circular, yellow colony, convex, entire	+	Cocci	+	-	-	-	*Staphylococcus epidermidis*
Week 2 Group A	Circular, yellow colony, convex, entire	+	Cocci	+	+	+	-	*Staphylococus aureus*
Week 2 Group B	Circular, yellow colony, convex, entire	+	Cocci	+	-	-	-	*Staphylococcus epidermidis*
Week 3 Group A	Circular, yellow colony, convex, entire	+	Cocci	+	+	+	-	*Staphylococus aureus*
Week 3 Group B	Circular, yellow colony, convex, entire	+	Cocci	+	-	-	-	*Staphylococcus epidermidis*
Week 4 Group A	Circular, yellow colony, convex, entire	+	Cocci	+	+	+	-	*Staphylococus aureus*
Week 4 Group B	Circular, yellow colony, convex, entire	+	Cocci	+	-	-	-	*Staphylococcus epidermidis*

Week 5 Group A	Circular, yellow colony, convex, entire	+	Cocci	+	+	+	-	*Staphylococus aureus*
Week 5 Group B	Circular, yellow colony, convex, entire	+	Cocci	+	-	-	-	*Staphylococcus epidermidis*
Week 6 Group A	Circular, yellow colony, convex, entire	+	Cocci	+	+	+	-	*Staphylococus aureus*
Week 6 Group B	Circular, yellow colony, convex, entire	+	Cocci	+	-	-	-	*Staphylococcus epidermidis*

Key: + = Positive, - = Negative
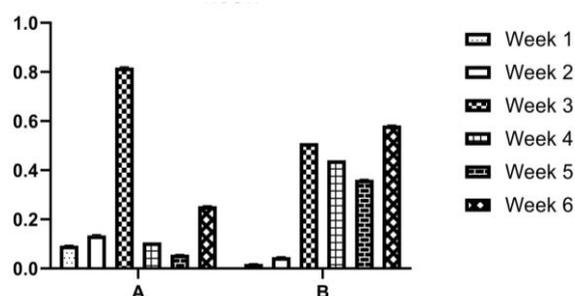
Figure 1: Level of formaldehyde (HCOH) in built air environment

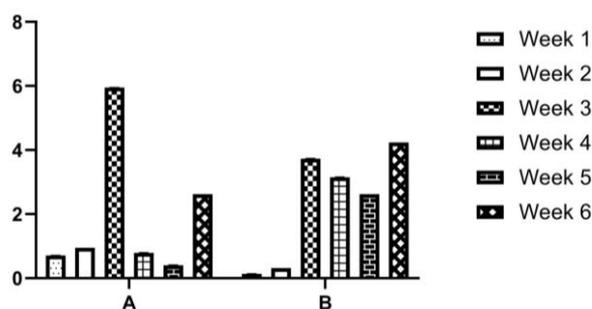Key: Group A = Office with air-conditioned system; Group B = Office with window system

Figure 2: Level of volatile organic compounds (TVOC) in built air environment

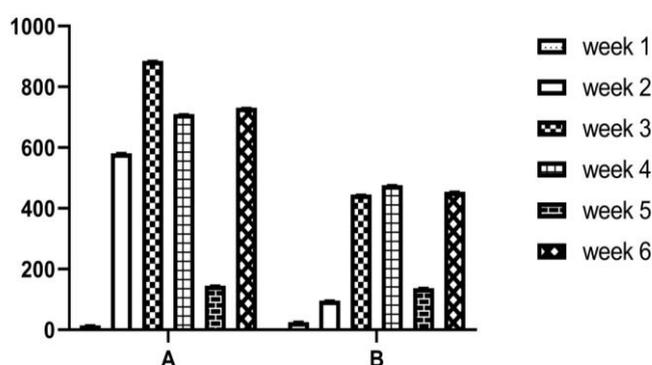Key: Group A = Office with air-conditioned system; Group B = Office with window system

Figure 3: Level of particulate matter (PM$_{2.5}$) (µg/m^3) in built air environment

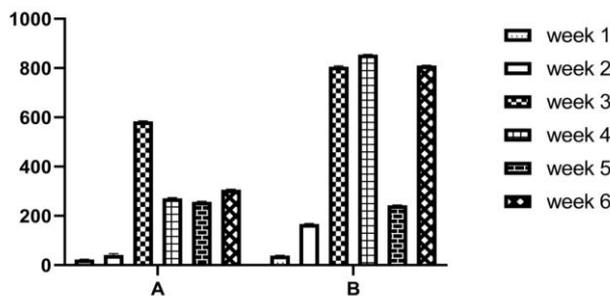Key: Group A = Office with air-conditioned system; Group B = Office with window system

Figure 4: Level of particulate matter (PM$_{10}$) (µg/m^3) in built air environment

Key: Group A = Office with air-conditioned system; Group B = Office with window system
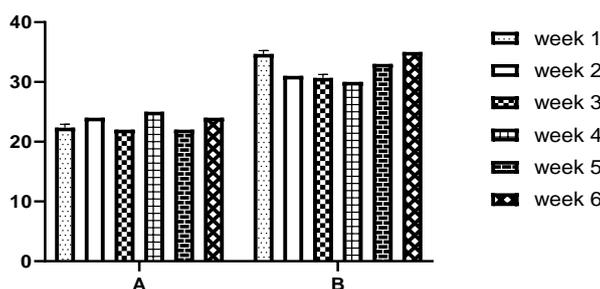

Figure 5: Level of temperature (°C) in built air environment

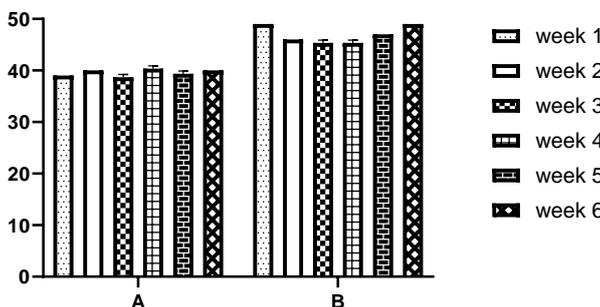Key: Group A = Office with air-conditioned system; Group B = Office with window system

Figure 6: Level of humidity (%) in built air environment

Key: Group A = Office with air-conditioned system; Group B = Office with window system

Table 4: Antibiotic sensitivity profiles of *Staphylococcus aureus*

SITE	SXT	E	PEF	CN	APX	Z	AM	R	CPX	S
Week 1a	21.00 ±0.57	38.33 ±1.66	39.66 ±0.88	29.66 ±0.66	0.00 ±0.00	0.00 ±0.00	19.33 ±1.20	32.66 ±1.76	36.33 ±2.02	26.00 ±1.00
Week 1b	40.00 ±0.57	0.00 ±0.00	39.66 ±2.60	0.00 ±0.00	40.33 ±0.33	0.00 ±0.00	20.00 ±0.00	0.00 ±0.00	38.66 ±3.48	0.00 ±0.00
Week 2a	19.00 ±0.57	26.00 ±1.73	30.33 ±0.33	29.33 ±1.20	24.33 ±0.33	23.66 ±1.76	27.33 ±1.45	21.66 ±1.20	29.00 ±1.00	24.66 ±1.45
Week 2b	25.00 ±0.57	27.00 ±1.73	29.00 ±1.15	28.33 ±1.76	25.00 ±1.15	22.00 ±1.00	26.33 ±0.33	28.66 ±1.85	21.33 ±0.88	22.66 ±0.33
Week 3a	19.00 ±0.57	27.00 ±0.00	34.33 ±1.76	28.66 ±0.66	23.66 ±1.76	0.00 ±0.00	0.00 ±0.00	23.00 ±0.00	27.66 ±1.45	28.66 ±0.33

Week 3b	20.00 ±0.57	28.66 ±2.02	34.33 ±0.33	0.00 ±0.00	0.00 ±0.00	0.00 ±0.00	0.00 ±0.00	42.00 ±1.52	34.00 ±0.00	28.00 ±0.00
Week 4a	31.66 ±0.66	29.66 ±2.02	28.66 ±0.66	21.00 ±0.00	22.66 ±2.66	20.66 ±0.33	21.00 ±0.00	22.33 ±1.33	32.00 ±2.08	30.66 ±2.33
Week 4b	24.00 ±2.08	0.00 ±0.00	38.66 ±0.00	0.00 ±0.00	0.00 ±0.00	0.00 ±0.00	20.00 ±0.00	20.00 ±1.73	0.00 ±0.00	28.66 ±0.88
Week 5a	30.66 ±2.33	25.00 ±0.00	34.00 ±0.00	26.33 ±2.33	23.33 ±2.02	25.00 ±1.73	23.00 ±2.30	21.00 ±0.00	28.33 1.20	26.66 ±0.88
Week 5b	26.66 ±1.66	27.33 ±1.76	27.66 ±0.33	25.33 ±1.45	22.00 ±0.00	26.33 ±7.35	0.00 ±0.00	20.00 ±1.73	27.33 ±0.66	27.00 ±1.00
Week 6a	21.00 ±0.00	25.66 ±1.76	21.66 ±0.66	22.66 ±1.45	18.00 ±0.00	0.00 ±0.00	0.00 ±0.00	0.00 ±0.00	25.00 ±1.15	28.00 ±1.00
Week 6b	26.33 ±2.33	25.00 ±0.00	27.00 ±0.00	23.00 ±0.00	20.66 ±1.45	0.00 ±0.00	16.00 ±2.08	0.00 ±0.00	26.33 ±0.66	27.33 ±1.45

Data are presented as Mean±S.E (n=3). Values with the same superscript letter(s) along the same column are not significantly different ($P<0.05$)

Key: Septrin (SXT) 30µg, Erythromycin (E) 10µg, Pefloxacin (PEF) 10µg, Gentamycin (CN) 10µg, Ampiclox (APX) 30µg, Zinnacef (Z) 20µg, Amoxacillin (AM) 30µg, Rocephin (R) 25µg, Ciproflaxacin (CPX) 10µg, Streptomicin (S) 30µg.
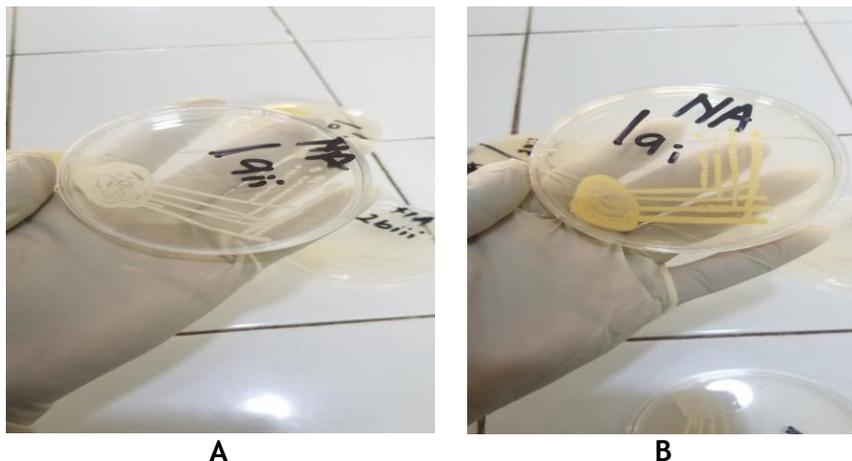

Plate 1: *Staphylococcus aureus* (A) and *Staphylococcus epidermidis* (B) growth on nutrient agar plates

DISCUSSION

The sick building syndrome has been associated with inhalation of organic dust that may contain microorganisms, volatile organic compounds, and allergens, which can affect the human skin, respiratory, and neurological systems, that may lead to nasal congestion, coughing, sneezing, and so on (Terr, 2009).

In this study, *Staphylococcus* spp. that ranged from 240 to 650 CFU/m^3 was found in air samples of built environments with air-conditioned system and built environments with open-window systems. This is in agreement with Madsen *et al*. (2018) that reported the presence of species of *Staphylococcus* in airborne dust of indoor air samples in Greater Copenhagen. Also, *S. aureus* was found in 100% of indoor air samples from living rooms

ranging from 4 to 140 CFU/m^3 (Moon *et al.*, 2014). Contrarily, studies of Madsen *et al.* (2018) reported low prevalence of airborne *S. aureus*.

Higher *Staphylococcal* counts were observed in built environments with air-conditioned system compared to offices with open-window systems. This may be due to confined air flow system that perhaps hinders outflow of anthropogenic airborne *Staphylococcus* spp. In general, it is known that about 20% of individuals are persistent carriers of *S. aureus*, and 60% are intermittent carriers (Kluytmans *et al.*, 1997). *Staphylococcal* spp. was isolated from air samples reported by Omoya *et al.* (2014); Andualem *et al.* (2019) and Olusola-Makinde (2020). The presence of *Staphylococcus aureus* and *S. epidermidis* could be due to high traffic in and out of the built environments, unhygienic surroundings due to irregular cleaning, and inefficient handwashing and other sanitization practices (Bashir *et al.*, 2016). *S. aureus* can also result to a wide variety of diseases in man and animals by the synthesis of toxin. Staphylococcal toxins are known cause of food poisoning; this is because the toxins are produced by bacteria commonly found in inappropriately kept food items (Willey *et al.*, 2008).

The study revealed progression in formaldehyde (HCHO) values in studied air environments. This may be due to presence of wooden furniture and paints within and outside the office space. Formaldehyde is part of the volatile organic compound category that easily evaporates under normal indoor conditions into the air from building materials, furniture, paints, and adhesives (Kristak *et al.*, 2023). Based on its volatility and associated health risks, HCHO readings are included in indoor air quality assessments.

The U.S. Environmental Protection Agency (EPA) has set a long-term exposure limit of 0.03 ppm for formaldehyde, indicating that while short-term exposure (measured at less than 30-min exposure) is acceptable, prolonged exposure should be minimized to avoid adverse health effects (Nielsen *et al.* (2017). The values of HCHO in both categories of studied air samples of built environments exceeded the recommended standards and may pose health risks to occupants having prolonged stay in such environments.

The total volatile organic compounds (TVOC) values in environment B with the open-air window system was higher than that of environment A with the air-conditioned system. Ilies *et al.* (2022) reported that high temperatures combined with low relative humidity induced a heightened stress which favour the lifting of suspended particles and the release by new construction materials of amounts above the permissible limit of formaldehyde and volatile organic compounds.

The study observed higher temperatures and comparatively low relative humidity of air samples from the studied built environments. This may be as a result of heat generating activities such as cooking and use of other heating appliances. The weather of the studied environment also recorded low relative humidity; the summer (about 80%). Higher temperatures and humidity levels can increase the rate of release of some VOCs from building materials and other sources, leading to higher TVOC levels. The study correlated with Ologbosere *et al.* (2023) that relative humidity (%) has a negative correlation with particulate matter.

The values of particulate matter (PM$_{2.5}$) of studied air samples at week 1 were low but increased steadily. It was also found that the values of PM$_{2.5}$ in built environment with open window system (78 µg/m^3) was lower than that of built environment with air-conditioned system (566 µg/m^3). These values were found to be higher than the revised

WHO Guidelines of 10 µg/m^3 for PM$_{2.5}$ and 20 µg/m^3 for PM$_{10}$. Prolonged exposure to levels above 50 µg/m^3 can lead to serious health issues and premature mortality (Sharma *et al.*, 2020). The values of PM$_{2.5}$ in studied air samples of built environments are thus considered unhealthy for weeks 2, 3, 4, 5, and 6. This may be due to influx of human movements and activities responsible for raised dusts, incorporated with reported high temperature. Temperature of above 15°C was found to favour the presence of PM$_{2.5}$ and PM$_{10}$ in the atmosphere with a V-Shaped characteristics (Ologbosere *et al.*, 2023).

The most prevalent type of *S. aureus* infection is skin infections such as small benign boils, folliculitis, impetigo, cellulitis, and more serious, invasive soft-tissue infections and eczema. The armpits, hair, and scalp are among the fertile, active areas where it is most commonly found.

The study observed that pefloxacin (10 µg) and ciprofloxacin (10 µg) were the most effective antibiotics showing the highest zones of inhibition against tested isolates. Resistance of *Staphylococcal* isolates to erythromycin (15 µg) and gentamycin (10 µg) was also recorded in the study. This is not in agreement with Olusola-Makinde (2020) and Ojo *et al.* (2024) that reported intermediate antibiotic activity and susceptibility of *Staphylococcus aureus* isolated from outdoor air samples of Akure abattoir to erythromycin (15 µg) and gentamycin (10 µg) respectively. Antibiotics such as ciprofloxacin (10 µg) that revealed consistent inhibition against *Staphylococcal* isolates could be recommended for the treatment of airborne infections related to *Staphylococcal* infection. *S. aureus* can result to a wide variety of diseases in man and animals by the synthesis of toxin (Olusola-Makinde, 2020).

CONCLUSION

The air quality of occupied built environments is key to public health and safety. The study identified *Staphylococcus* spp. in numbers considered unsafe for long exposure. The volatile organic compounds levels observed in the study were indicated poor quality of studied air environments. Some of the *Staphylococcus aureus* isolates were resistant to tested antibiotics such as erythromycin (15 µg) and gentamycin (10 µg). The study displayed the need for routine monitoring and disinfection of air environment in built spaces especially when the traffic is high and occupants spend long hours indoor. Susceptibility of isolates to drugs such as ciprofloxacin that incite its recommendation against related airborne infections.

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