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***Corresponding author**
Chiamaka Chikwem
E-mail
chikwem.chiamaka@mouau.edu.ng

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Microbial Air Quality Assessment of a Tertiary Hospital in Makurdi, North-Central Nigeria

Chiamaka Chikwem[1]*, Celestine U. Aguoru[2], Thomas Okoh[2], Chizoba S. Onuora[3], Osinachi M. Ozioko[4]

[1]Department of Environmental Science, Joseph Sarwuan Tarka University, Makurdi, Nigeria
[2]Department of Plant Science and Biotechnology, Joseph Sarwuan Tarka University, Makurdi, Nigeria
[3]Quality Control Analyst, Chanelle Pharma, Galway, Ireland
[4]Centre for Environmental Management and Control, University of Nigeria, Nsukka, Nigeria

Abstract

The levels of airborne bacteria and fungi in the environment of a tertiary hospital in Makurdi, North-Central Nigeria were assessed within 10 selected areas/conditions: theatre at rest (TAR), electrosurgery (ES), inhalational anesthetics (IA), electrosurgery + inhalational anesthetics (ESIA), back of the hospital (BACK), front of the hospital (FRONT), generator house area of the hospital (GEN-H), accident and emergency ward (A&E), intensive care unit (ICU), and microbiology lab (M-LAB). Measurements of the temperature and relative humidity of the sampled areas were also taken. The results were then compared with international microbial air quality guidelines. Mean relative humidity exceeded limits in TAR, ES, ESIA, FRONT, A&E, and M-LAB. Mean bacterial total viable counts (TVCs) exceeded acceptable limits in 5 of the areas assessed (ES, IA, A&E, M-LAB, and GEN-H) while mean fungal TVCs also exceeded acceptable limits in 5 areas (ES, A&E, M-LAB, FRONT, and GEN-H). The most commonly found bacteria were *Staphylococcus aureus* and *Cyanobacterium*, while the most commonly found fungal species were species of *Aspergillus* and *Candida albicans*. The presence and exceedance of both bacterial and fungal species may result from high relative humidity, the number and activities of occupants in such environments, ineffective disinfecting agents, cleaning frequencies or methods, and/or resistance to their antimicrobial activity. It is recommended that hospital management ensure that the operating theatre (OT) and other departments have adequate air conditioning and ventilation, and regularly assess and evaluate their air to ensure that it is healthy for hospital occupants.

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Introduction

Microbial air quality is the degree to which air within and around a specific location is free from microbial contaminants that are capable of negatively affecting human health. Microbial air contaminants or pollutants are microbes, including fungi, bacteria, viruses, algae, as well as their spores and derivatives, present both inside and outside non-industrial environments that possess the ability to cause disease [1]. Most microbial air contaminants are either airborne bacteria or airborne fungi. This study is particularly concerned with airborne bacteria and fungi that are commonly associated with diseases of humans (human airborne pathogens) [2].

Human exposure to airborne pathogens usually occurs by inhalation and by contact with the mucous membranes of the respiratory system [2]. Microbial air contaminants have been linked to various adverse health issues such as diseases and disorders of the eye, nose, throat, respiratory system, and skin [3-5]. Thus, the presence of microbial air contaminants in a building or location can adversely affect the air quality of that area as well as the health and wellness of individuals present in that location, thereby constituting a public health challenge [6]. The predominant aerobacteria found in hospital environments include species of *Bacillus, Enterobacteriaceae, Micrococcus luteus, Pseudomonas, Streptococcus,* and *Staphylococcus aureus* [6-8], while airborne fungi are predominantly moulds such as species of *Aspergillus, Penicillium, Rhizopus, Cladosporium,* and yeasts such as *Candida* [9, 10].

Poor microbial air quality in healthcare institutions adversely impacts patients' health, safety, and comfort [11] as well as the all-around health and productivity of hospital staff [12], which consequently has both short-term and long-term negative cost implications for the hospital involved. The presence and concentrations of airborne microbes, especially indoors, are determined by certain factors such as carriers or reservoirs, ventilation, moisture or humidity, and temperature [12-14]. Due to the important roles of hospitals in the prevention, control, and management of diseases and disorders, they are obliged to establish and maintain a healthy and conducive environment for their occupants (staff, patients, and caregivers) [7, 15]. Ensuring that their microbial air quality is satisfactory and does not adversely affect the health of hospital occupants or increase the risk of hospital-acquired infections (HAIs) is an important way hospitals can achieve this obligation [12, 16]. The tertiary hospital chosen for this study is the largest hospital in Makurdi, which is approved by the Medical and Dental Council of Nigeria (MDCN) to train medical doctors and run residency programmes, and it also serves as a referral centre for both primary and secondary healthcare institutions [17, 18].

This study aimed to assess the levels of microbial air contamination in the confines of the hospital using sensitive and specialised indoor and outdoor environments as sampling areas, and to ascertain if their air quality met acceptable guidelines. It will aid hospitals, especially those in developing countries like Nigeria see the need to pay better attention to and improve the air quality of their environments and provide qualitative and up-to-date data essential for the control and management of microbial air contamination and hospital-acquired infections (HAIs).

Materials and Methods

Ethical clearance

Ethical clearance and letters of introduction to carry out this study were applied for and obtained from the Health Research and Ethics Committee (HREC) of the hospital, while informed consent was obtained from the department Heads of all the sampled areas. For this study, sampling was undertaken in the following departments: 1. The operating theatre (OT) under four different conditions: a. theatre at rest (TAR), b. electrosurgery (ES), c. inhalational anaesthetics (IA), and d. electrosurgery+inhalational anaesthetics (ESIA); 2. back of the hospital (BACK), 3. front of the hospital (FRONT), 4. generator house area of the hospital (GEN-H), 5. accident and emergency ward (A&E), 6. intensive care unit (ICU), and 7. microbiology lab (M-LAB).

Measurements of temperature and relative humidity

A mini thermo-anemometer (Thomas Scientific model) was used to measure temperature and relative humidity of the sampled areas [19]. It was adequately pre-calibrated and fully powered. It was held at a height of about 1.5 m above the ground, which represents the breathing zone, and at least 1 m away from the wall.

Sampling and analysis for key indoor microbial air contaminants

Sampling for microbial air contaminants was carried out using a passive method [3]. Petri dishes were

prepared in triplicate for reproducibility and to improve accuracy. The mean values were reported. The average number of occupants present during the period of sampling per location was also recorded. Samples of airborne bacteria and fungi were collected daily in triplicate to be assessed over two weeks per hospital. Blood agar (BA), chocolate agar (CA), and Sabouraud dextrose agar (SDA) were prepared according to the manufacturer's instructions and sterilised in an autoclave at 121 °C for 15 minutes. Around 30 ml of each culture media were poured into 9 cm Petri dishes separately and allowed to solidify. BA and CA were used to culture the bacteria, while the SDA will be used for the fungi. Each Petri dish was left open in the sampling site for 1 hour, at least 1 m from the floor and at least 1m away from walls or any other barriers [5], after which the dishes were covered, sealed, and incubated. The BA and CA plates were incubated for 24 to 48 hours at 37 °C, while those containing SDA were put in an incubator for 72 hours at 28.5 °C [6]. The colonies were counted with a colony counter and expressed as colony-forming units per cubic metre (cfu/m^3) of air. The total viable counts (TVC) in cfu/m^3 will be calculated using Omeliansky's formula:

$N = 5a \times 10^4/(bt)$

Where
N = microbial cfu/m^3 of air,
a = number of colonies per Petri dish;
b = surface area of dish in square centimetres; and
t = time of exposure in minutes [20]

The mean values were compared with the WHO and ACGIH guidelines for IAQ (biological contaminants) [1, 21] and the NESREA guidelines for ambient (outdoor) air quality [22].

Isolation and identification of bacteria and fungi

The colonies of airborne bacteria yielded using BA and CA were first identified based on their characteristics on the culture medium, after which they were Gram-stained and observed under a microscope for further identification of individual organisms. The bacteria were also identified based on their biochemical properties using biochemical tests [4]. The airborne fungi colonies produced using SDA were identified based on their colonial characteristics. They were further subjected to Lactophenol cotton blue staining and microscopy to identify the morphology of individual fungi and spore formation [4].

Data analysis

The results produced from the assessment were statistically analysed using Minitab 17.0 and one-way ANOVA at 95% confidence level (0.05 level of significance).

Results

In BSUTH, mean temperatures ranged from 22.2°C in TAR to 32.1°C in GEN-H. The hottest areas were all outdoor environments, namely GEN-H (32.1°C), BACK (29.2°C), and FRONT (28.3°C). Conversely, the coolest areas were specialised indoor environments, namely TAR (22.2°C), ES (23.5°C), and ICU (23.8°C). In addition to the hottest

Table 1 Mean temperature, relative humidity, and number of occupants in each of the sampled areas.

Area	Temperature (°C)	Relative humidity (%)	Number of occupants
Theatre at rest (TAR)	22.2± 0.15	68.0±1.53	2
Electrosurgery (ES)	23.5±0.06	54.3±1.20	15
Inhalational anaesthetics (IA)	24.6±0.06	44.3±0.33	12
Electrosurgery+inhalational anaesthetics (ESIA)	24.8±0.15	52.0±1.53	14
Back of the hospital (BACK)	29.2±0.09	22.0±1.15	2
Front of the hospital (FRONT)	28.3±0.12	53.0±1.15	9
Generator house area of the hospital (GEN-H)	32.1±0.12	35.0±1.53	1
Accident and emergency ward (A&E)	27.7±0.20	64.3±0.33	26
Intensive care unit (ICU)	23.8±0.21	45.3±0.89	4
Microbiology lab (M-LAB)	28.3±0.12	56.0±0.58	10

Table 2 Microbial air quality guidelines used for this study.

Regulatory Agency	Indoor/Outdoor	Bacteria/Fungi	Threshold
ACGIH	Indoor	Bacteria	100 cfu/m^3
WHO	Indoor	Fungi	150 cfu/m^3
NESREA	Outdoor	Bacteria	500 cfu/m^3
NESREA	Outdoor	Fungi	500 cfu/m^3

environments, A&E and M-LAB, which were indoor environments, also exceeded the acceptable limit of 25°C. Thus, two indoor environments and three outdoor environments exceeded the limit (Table 1). Mean relative humidity (RH) ranged from 22.0% in BACK to 68.0% in TAR. The most humid environments were TAR (68.0%), A&E 64.3%), and M-LAB (56.0%). The least humid areas were BACK (22.0%), GEN-H (35.0%), and IA (44.3%). In addition to the most humid environments, ES, ESIA, and FRONT also exceeded the limit of 50%. Thus, six environments were unacceptably humid, of which FRONT was the only outdoor environment that exceeded the limit, while the other five environments were indoor environments. The average number of occupants in the hospital ranged from 1 person in GEN-H to 26 persons in A&E. Thus, the most crowded areas were A&E (26 persons), ES (15 persons), and ESIA (14 persons), while the least populated were GEN-H (1 person), TAR, and BACK (2 persons each). Thus, A&E, ES, and ESIA can be said to be overcrowded.

It is recommended that indoor airborne bacterial concentrations should not exceed 100 cfu/m^3 per hour of exposure [21] while indoor airborne fungal concentrations should not exceed 150 cfu/m^3 per hour of exposure [1]. For outdoor environments, both airborne bacteria and fungi should not exceed 500 cfu/m^{3,} respectively [22] (Table 2). Mean bacterial TVCs ranged from 30 cfu/m^3 in (TAR) to 1030 cfu/m^3 in A&E. Thus, TAR (30 cfu/m^3), ICU (86 cfu/m^3), and ESIA (97 cfu/m^3) had the lowest bacterial counts, while A&E (1030 cfu/m^3), GEN-H (583 cfu/m^3), and IA (500 cfu/m^3) had the highest bacterial counts (Table 3). Exceedance of the acceptable limits occurred in five of the ten environments assessed, of which one was an outdoor environment (GEN-H), while the other four were indoor environments, namely ES, IA, A&E, and M-LAB. Mean fungal TVCs ranged from 25 cfu/m^3 in TAR to 703 cfu/m^3 in FRONT. Thus TAR (25 cfu/m^3), ESIA (67 cfu/m^3), and IA (117 cfu/m^3) had the lowest counts, while FRONT (703 cfu/m^3), GEN-H (560 cfu/m^3), and M-LAB (322 cfu/m^3) had the highest counts. In this case too, exceedance of the acceptable limits occurred in five of the ten environments assessed, but two were outdoor environments namely FRONT and GEN-H, while the other three were indoor environments namely ES, A&E, and M-LAB (Table 3). There were five organisms isolated in total, namely two bacteria (*Staphylococcus aureus* and *Cyanobacterium)* and three fungi *(Aspergillus niger, Aspergillus fumigatus*, and *Candida albicans* (Table 4). Concerning the bacteria, *Staphylococcus aureus* was detected in all the areas assessed, except in A&E. A&E was also the only environment where *Cyanobacterium* was detected. Of the fungi isolated, *Aspergillus niger* was detected in six out of the ten environments, namely BACK, FRONT, GEN-H, A&E, ICU, and M-LAB, while *Aspergillus fumigatus* was detected in two areas (TAR and IA), and *Candida albicans* was detected in the other two environments, namely ES and ESIA.

Table 3 Mean microbial TVCs in each of the Sampled Areas and their exceedance of microbial air quality guidelines used for this study.

Microbes	TAR (Indoor)	ES (Indoor)	IA (Indoor)	ESIA (Indoor)	BACK (Outdoor)	FRONT (Outdoor)	GEN-H (Outdoor)	A&E (Indoor)	ICU (Indoor)	M-LAB (Indoor)
Bacteria	30	443	500	97	131	423	583	1030	86	294
Exceedance	No	Yes	Yes	No	No	No	Yes	Yes	No	Yes
Fungi	25	210	117	67	117	703	560	277	136	322
Exceedance	No	Yes	No	No	No	Yes	Yes	Yes	No	Yes

Values are in colony-forming units per cubic metre (cfu/m^3). Exceedance (of recommended threshold): Yes (within the threshold), No (above the threshold).

Table 4 Microbial isolates detected in the hospital by sampling area.

Area	Bacteria	Fungi
Theatre at rest (TAR)	*Staphylococcus aureus*	*Aspergillus fumigatus*
Electrosurgery (ES)	*Staphylococcus aureus*	*Candida albicans*
Inhalational anaesthetics (IA)	*Staphylococcus aureus*	*Aspergillus fumigatus*
Electrosurgery+inhalational anaesthetics (ESIA)	*Staphylococcus aureus*	*Candida albicans*
Back of the hospital (BACK)	*Staphylococcus aureus*	*Aspergillus niger, Candida albicans*
Front of the hospital (FRONT)	*Staphylococcus aureus*	*Aspergillus niger, Candida albicans*
Generator house area of the hospital (GEN-H)	*Staphylococcus aureus*	*Aspergillus niger, Candida albicans*
Accident and emergency ward (A&E)	*Cyanobacterium*	*Aspergillus niger, Candida albicans*
Intensive care unit (ICU)	*Staphylococcus aureus*	*Aspergillus niger*
Microbiology lab (M-LAB)	*Staphylococcus aureus*	*Aspergillus niger, Candida albicans*

Discussion

A high number of occupants, in addition to temperatures and relative humidity which were above limits in A&E and M-LAB, may have contributed to the high bacterial counts in A&E as well as the high fungal counts in M-LAB. Most of the occupants in those areas were involved in activities such as talking, laughing, and walking, which are known to increase the concentrations of microbes in indoor air [11, 24]. The dominant bacterial species were *Staphylococcus aureus* which was isolated from theatre (TAR, ES, IA, ESIA), outdoors (FRONT, BACK, GEN-H) and ICU, and *Cyanobacterium* sp. which was isolated from A&E. TAR, ICU and ESIA were the areas with the lowest bacterial counts due to being located in specialised indoor environments, having very low occupancy and efficient air conditioning. A&E had the highest mean bacterial count, which may be a result of very high occupancy, limited air conditioning, and ventilation [3, 24]. GEN-H had very low occupancy (1 occupant), but it had the highest mean temperature; there was no air conditioning, and ventilation was limited, bringing about low dispersion and high concentration of bacteria in the atmosphere of the GEN-H environment. IA is in the OT and had the third highest bacterial count because it had high occupancy (12 occupants, which was the fourth highest in the hospital), the second highest temperature in the OT environment, and the air conditioning was not functioning properly in that area during the assessment period, as shown in previous studies [6, 14]. For the indoor environments, 4 of 7 areas assessed exceeded acceptable limits (ES, IA, A&E, and M-LAB), with only TAR, ESIA, and ICU meeting accepted limits. This exceedance may be a result of the high occupancy and high relative humidity in such environments, which can increase the concentrations of airborne microbes indoors [9, 10]. Outdoors, only GEN-H exceeded accepted limits.

The dominant fungal species were *Aspergillus* spp. *(A. niger* was isolated from A&E, ICU, FRONT, BACK, and GEN-H, while *A. fumigatus* was isolated from TAR and IA) and *Candida albicans* which was isolated from ES, ESIA and A&E. TAR, ESIA and IA had the lowest fungal counts because all 3 areas are in the OT environment where there was relatively low occupancy, efficient air conditioning and cooler temperatures. FRONT and M-LAB had the highest fungal counts because of the high number of occupants who were constantly moving around, limited air conditioning, and limited ventilation [1, 2]. GEN-H had the second-highest fungal count because, despite very low occupancy (1 occupant), it had the highest mean temperature in the hospital; there was no air conditioning, and ventilation was limited, bringing about low dispersion and high concentration of fungi in the atmosphere of its environment [7, 8]. Of the 7 areas assessed indoors, 3 areas, namely ES, A&E, and M-LAB, exceeded acceptable limits. Outdoors, 2 of the 3 environments assessed, namely FRONT and GEN-H, exceeded acceptable limits. The presence and exceedance of both bacteria and fungi species in the indoor air of the healthcare institutions assessed, despite using different sterilants and disinfectants, may be due to ineffective sterilising or disinfecting agents, frequencies or methods, and/or resistance to their antimicrobial activity, which enables them to survive and persist in the hospital environment. Their presence may also be due to the presence, number, and activities of occupants in such environments. Such exceedance can increase the rate of hospital-acquired infections and other adverse health effects in patients as well as staff. Thus, the levels of microbial air contamination exceeded WHO [1] and ACGIH [21] guidelines in the indoor environments, and NESREA guidelines [22] in the outdoor environments. This study is in agreement with previous reports [5, 7], where *Staphylococcus* and *Aspergillus* were among the dominant microbes and in some other reports, the dominant fungal species detected in the indoor air of the hospital assessed were species of *Aspergillus* and *Candida* [8, 10].

Conclusion

Despite the tertiary hospital investigated in this study being regarded as one of the best hospitals in North-Central Nigeria in terms of quality of facilities, staff, and service delivery, the microbial air quality of its environment was not satisfactory. Such low microbial air quality can put the health and safety of hospital occupants at great risk, especially patients with weak or compromised immunity, and undermine the efforts and reputation of the hospital and its staff. Therefore, it is recommended that healthcare staff should reduce activities that increase the concentrations of microbes in the air to the barest minimum. Antimicrobial agents and methods that have very low toxicity to humans but are very effective for disinfection or sterilisation should be discovered and utilised. Most importantly, hospital management should ensure that the operating theatre

(OT) and other special units or departments have adequate air conditioning and ventilation, and regularly assess and evaluate the hospital air quality to ensure that it is healthy for hospital occupants.

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Competing Interests

The authors have no financial or non-financial interests to disclose directly or indirectly linked to the work.

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