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The impact of a disinfection intervention on the microbial indoor air quality at a university library

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ABSTRACT

Introduction: Indoor environment contributes to human health and productivity. The absence of climatic control systems may lead to microbial contamination. The air quality of public institutions should be monitored. Therefore, this study was conducted to determine the microbial load of the air in the main library at the University of Guyana and to evaluate the effectiveness of a disinfection intervention on the microbial load of the air.

Materials and methods: This was an experimental- observational study involving three phases: analyzing the microbial quality of the air, a disinfection experiment, and a disinfection intervention. Phase 1 was done before the rehabilitation of the library, Phase 2 was done during the rehabilitation, and Phase 3 was carried out after the rehabilitation and the disinfection intervention. Samples were collected on settle plates and incubated. Colony-Forming Units (CFUs) were enumerated and the microbial load was determined using a standardised equation. Several disinfectants were tested against two bacteria and a specific disinfection protocol was developed for the disinfection intervention.

Results: The bacterial load for Phase 1 (13,114 CFU/m^3) and Phase 2 (7,636 CFU/m^3) was higher than that of Phase 3 (4,648 CFU/m^3). There was an extremely high fungal load (4,067 CFU/m^3) before the disinfection intervention but no growth after.

Conclusion: We concluded that a high microbial load was found in our study before the disinfection intervention which was considerably diminished after the intervention. We recommend implementing the cleaning regimen we developed as part of the library's cleaning protocol.

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Introduction

The University of Guyana (UG) Main Library is the second largest library in the country and is analyzed by many staff and students as well as students and teachers from secondary schools. Therefore, it is important that its users, be provided with a safe indoor environment. The indoor environment contributes to human health and well-being; and ultimately their productivity [1]. The air quality of the indoor atmosphere is greatly affected by various microorganisms including bacteria, viruses, and molds [2]. These airborne microorganisms are referred to as bioaerosols. Bioaerosols are produced when people sneeze, cough, talk and walk. They are also produced via indoor plants, foods, beverages, dust, rugs, wood material and furniture, and many others [3].

The modern man spends 90% of his time inside confined spaces, 50% in dwellings and 30% in workplaces [4]. Indoor dwellers breathe 10m^3 of air per day on average and as such they are often exposed to bioaerosols [5]. The quality of air a person breathes is of great significance because it can directly or indirectly cause infections and diseases [6] most of which, affect respiratory health [7].

Respiratory infections include pharyngitis, tonsillitis, epiglottitis, bronchitis and bronchiolitis, and pneumonia. They are caused by bacteria like *Mycobacterium tuberculosis, Staphylococcus aureus, Streptococcus pyogenes, Streptococcus pneumoniae, Corynebacterium diphtheriae, Mycoplasma pneumoniae, Mycoplasma hominis, Haemophilus influenzae, Klebsiella pneumoniae, Escherichia coli, Pseudomonas aeruginosa, Neisseria sp., Chlamydia sp., Legionella sp., etc.* [8]. They may also be caused by fungi like *Aspergillus sp., Cryptococcus neoformans, Candida sp., Histoplasma capsulatum; Blastomycetes sp., Coccidioides sp.*, and *Paracoccidioides sp.* Viruses also cause respiratory infections and include Rhinovirus, Coronavirus, Adenovirus, Influenza virus, Respiratory Syncytial virus, and many others [8]. Bacteria such as *Staphylococcus aureus, Streptococcus pyogenes, Bacillus sp., Neisseria sp., and Micrococcus sp.*, and fungi such as *Alternaria sp., Cladosporium sp., Aspergillus sp.*, and *Penicillium sp.* were found in a University library [9].

Most indoor rooms are fully or partially closed thereby creating an environment that is poorly ventilated, highly humid, and odorous, which in turn gives rise to an abundant microbial population including fungal spores and molds [10]. Human activities, environmental factors, and building infrastructure contribute to the buildup and reproduction of airborne microbes [11]. Factors such as temperature, humidity, airflow, age of the building, building type and location, design, and ventilation system influence the growth and multiplication of indoor microbes. Epidemiological studies have shown that there is a correlation between indoor dampness-related factors and a variety of effects on respiratory health [10].

Previous studies have demonstrated that high numbers of airborne microbes are present in storage and conservatory places including libraries and museums [12]. Microbial contamination of library collections and buildings is significant since mold is a major problem for collections, buildings, and historical objects. More importantly, bacterial endotoxins and mycotoxins are a threat to the health of the people dwellings in these places. Many public places, including libraries, are not financially equipped to install proper ventilation and climate control systems to prevent the development and spread of microbes. Therefore, the air quality of public institutions should be monitored according to Article L221-8 of the Environmental Code [13].

Guyana is a tropical country and therefore there must be systems in place to regulate the indoor temperature of the UG Library. However, the prioritisation of financial resources has affected the installation of proper ventilation and

climate control systems. The absence of these climatic control systems may lead to microbial contamination and the periodic reappearance of molds in libraries [14].

An observation of foot traffic over a period of time shows that at least 50 students use the Library, daily. The main library was selected for this study because it is used by many students and, like any enclosed area, is expected to contain a large number of microorganisms which could be detrimental to the health of its occupants, as well as deteriorate the building's wood and documentary heritage. Furthermore, staff complained about the unpleasant odor in some areas and a few of them reported having respiratory issues. The Caribbean Research Library (CRL), a large reference collection area, that stored historic documents, was closed for some time because of the odor and poor circulation of air and was earmarked for rehabilitation.

The objective of this study was to determine the microbial load of the air in the main library at UG, to test several disinfectants and determine the most effective ones to be used in a disinfection intervention and then to evaluate the effectiveness of the disinfection intervention on the microbial load of the air in the Library. This was achieved by randomly sampling areas on every level of the library and by observing how infrastructural and environmental factors contribute to the microbial load in the indoor air. The first phase of this study highlighted the priority areas for rehabilitation and disinfection. The last phase of this study revealed the effectiveness of the disinfection intervention we developed and the possibility of future recommendations for the same.

Overall, this study widens the scope of understanding on the microbial load of indoor air in public places such as libraries that can in turn contribute to the spread of respiratory infections. It also speaks to the importance of effective and consistent cleaning regimens for indoor buildings to lower microbial loads in indoor air and subsequently limit the spread of respiratory infections.

Materials and methods

Study design

This was a cross-sectional, observational study involving three phases of microbial Air Quality Testing (AQT), a disinfection experiment, and a disinfection intervention. This study followed a cross-sectional study design to collect and analyze observational data. Original numerical data was collected by observing the results from the AQT, the disinfection experiment, and the disinfection intervention. The data analysis was carried out using both descriptive and statistical methods.

Preparation of media

Nutrient Agar (NA) plates were used to perform the bacterial air quality testing (AQT), while Sabouraud Dextrose Agar (SDA) was used to perform the fungal AQT of the Main Library at the University of Guyana.

Nutrient agar (NA)

This mediium was prepared by using a composition of 32.5g powdered NA and 1.5 L of distilled water. A homogenous mixture was then prepared by heating and continuously stirring the mixture in a conical flask. The mixture was then autoclaved for about 20 m at 121^{o}C. The mixture was allowed to cool and then aseptically poured into sterile petri dishes. The media in the petri dishes were allowed to solidify for several hours in a sterile area. Solidified NA plates were placed in the refrigerator until needed. Sterility checks were conducted on the NA plates.

Sabouraud Dextrose Agar (SDA)

This medium was prepared by using a

composition of 21.7g powdered SDA and 0.3L of distilled water. A homogenous mixture was then prepared by heating and continuously stirring the mixture in a conical flask. The mixture was then autoclaved for about 20 m at 121°C. The mixture was allowed to cool and then aseptically poured into sterile petri dishes. The media in the petri dishes were allowed to solidify for several hours in a sterile area. Solidified SDA plates were placed in the refrigerator until needed. Sterility checks were conducted on the SDA plates.

It must be noted that only a limited quantity of SDA plates was available. We checked for the fungal aerosols only in the CRL of the library because this part of the library was inactive for quite some time and appeared to be in a deplorable state.

Sampling technique

Samples were collected using the passive air sampling technique. This technique involves the use of standard Petri dishes (90mm in diameter) with media called settle plates. Bioaerosols were collected using settle plates. Settle plates were carefully labeled, opened, and placed in various positions for approximately 1 h.

Sampling areas

All samples in this study were collected from the Main Library at the Turkeyen campus between November 2017 to August 2018. These samples were collected from the various locations within the building. Samples were collected from various locations on all three levels of the Library. For the ground floor, four areas were sampled namely the acquisition area, the common room, the reading room, and the information desk area in all three phases of AQT. For the second floor, four areas were also sampled namely the office complex, circulation area, reading room, and the Law & Social Science area in all three phases of the AQT. For the top floor, four areas were sampled in a particular area called CRL and two from the Science and Technology area for Phases 1 and 3. However, two additional samples were collected from CRL in Phase 3 AQT.

Air quality testing

Three phases of AQT were conducted at the main library at the Turkeyen campus. Phase 1 was done prior to some rehabilitation work in the library and Phase 2 was done during the process of the rehabilitation. Phase 3 was carried out after the rehabilitation and the disinfection intervention. The library was opened for use by students only, when Phase 1 testing was carried out. Phase 1 was done near the end of 2017, Phase 2 in early in 2018 and Phase 3 mid 2018. Settle plates were placed in the same area for each phase of the experiment. A total of 14 areas were investigated in Phase 1, 16 in Phase 2, and 14 in Phase 3.

Transportation and incubation

After 1h, settle plates were carefully closed and transported to the College of Medical Sciences Laboratory within 15 m. NA settle plates were incubated at 37°C, for 18-24 h in an incubator, and SDA settles plates were incubated at room temperature for 48 h to facilitate the longer incubation period for fungi.

Enumeration of microbes

After incubation, colony-forming units (CFU) were enumerated. One CFU represented the presence of a single microbial cell settling on the agar surface; therefore the number of colonies counted would be equivalent to the number of microbes that settled on each settle plate. The microbial load (CFU/m^3) was determined using the Omeliansky equation: $N=5a\times10^4(bt)\ -1$, where N = microbial CFU/m^3 of indoor air; a = number of colonies on settle plate; b = petri dish surface (10cm^2) and t = exposure time (60 m) [15].

Standard/Guidelines for microbial quality of indoor air

Three of the most appropriate standards/ guidelines for microbial quality of indoor air were selected to be used against the microbial load we found. The Sanitary Standard of the European Commission (SSEC) (1993) for non-industrial buildings was used for the first comparison. It states that < 50 CFU/m^3 is considered a "Very low" bacterial load, 50 - 100 CFU/m^3 is "Low", 100 - 500 CFU/m^3 is "Intermediate", 500 - 2000 CFU/m^3 is "High" and ≥ 2000 CFU/m^3 is a 'Very High' bacterial load [16]. This standard also states that < 25 CFU/m^3 is considered a "Very low" fungal load, 25 - 100 CFU/m^3 is "Low", and the other parameters are the same as for bacteria.

The second standard is the American Conference of Governmental Industrial Hygienists (ACGIH) which states that the normal air quality level is less than 500 CFU/ m^3 per sample [17]. The third standard/guideline used was put forth by WHO. According to them, the exposure guidelines for indoor environments are 1000 CFU/m^3 for indoor environments [18].

The disinfection experiment

Several disinfectants were tested to determine the most effective ones against Salmonella & Bacillus. Bacillus is a spore former and spores are the most difficult to eradicate and Salmonella causes food poisoning. Pure disinfectants, 5% and 10% dilutions used. Five (5) ml of the disinfectant solution was pipetted into a sterile test tube and then 0.5 ml of the bacterial culture was added. The test tube was shaken gently to distribute the organisms uniformly and the time was noted. One loopful of disinfectant-culture mixture was transferred to a section of a quarto NA plate at intervals of 2, 5, 10 and 15 m and the plates were incubated at 35-37^{o}C for up to 48 h. An NA plate was directly inoculated with the bacterial culture and used as a Control. Results were recorded on a spreadsheet.

The disinfection intervention

Three disinfectants were selected, based on effectiveness and cost, to carry out the disinfection intervention which was done before Phase 3 sampling. Cleaning and disinfection as well as the rehabilitation work were conducted for several weeks prior to sample collection. On the day of sample collection, cleaning and disinfection were done in the morning for most areas and after lunch for some areas. Samples were collected at 2 PM after the cleaning and disinfection was completed. A specific protocol was provided (Table 1), and the library cleaners carried out the disinfection.

Data analysis of samples

The observations and results from this study are presented empirically in the form of graphs and tables. Data analysis was done using Microsoft Excel 2007 and SPSS version 27. For the statistical analysis, only results that were obtained for the same areas for all three phases were included. For areas where sampling was not for done for a particular phase, because of suspected contamination or limitation of media, etc.; it was excluded. Statistical testing was only done for bacterial load of the indoor air in the library.

The Kolmogorov-Smirnov and Shapiro-Wilk tests were run to determine if the data was normally distributed (Table 2). However, it was not and therefore the non-parametric Kruskal-Wallis H test was used to determine if there were statistically significant differences between the phases of the AQT and the levels in the library.

Table 1. Disinfection protocol used prior to phase 3 AQT

Selected area	Actual cleaning &disinfecting method	Recommended cleaning & disinfection frequency for disinfection intervention	Recommended cleaning &disinfection frequency in future
Shelves	Spray and wipe with Clorox clean up.		Twice weekly
Cupboards	Spray and wipe with Clorox clean up.		Twice weekly
Walls & windows	Apply bleach and wipe after 30 seconds.	9 am	Weekly
Floors	Mop with Pine sol.		Daily (morning & afternoon)
Doors	Spray and wipe with Clorox clean up.	Sample collection @ 11 am	Weekly
Tables and chairs	Apply Clorox clean up. Wipe and clean after 30 seconds.		Twice Daily
Books	Vacuum or wipe with soft cloth or magnetic dusting cloth depending on the type of book.		As often as possible (Probably every fortnight)
Any other area	Spray and wipe with Clorox clean up or Apply bleach and wipe after 30 seconds depending on the area.		
Air freshener	Spray Lysol around the room.		Twice daily

Null hypothesis

1. There is no statistically significant difference between the bacterial loads across the different phases of the AQT.

2. There is no statistically significant difference between the bacterial loads across the different levels in the library.

Alternative hypothesis

1. There is a statistically significant difference between the bacterial loads across the different phases of the AQT.

2. There is a statistically significant difference between the bacterial loads across the different levels in the library.

Results and discussion

Bacterial load of the indoor air in the library

Fig. 1 and Table 3 show that the total bacterial load for Phase 1 (13,114 CFU/m^3) and Phase 2 (7,636 CFU/m^3) was higher than that of Phase 3 (4,648 CFU/m^3). The bacterial load between the different areas varied for the different phases. The ground level had the highest microbial load (6,640CFU/m^3) overall, particularly the Common room (3,071CFU/m^3). The microbial load for Phases 1 and 2 was higher for most areas sampled when compared to Phase 3. For example, the Acquisition area on the ground level had 1,245 CFU/m^3 (High) and 996 CFU/m^3 (High) in Phases 1 and 2 respectively, and only 498 CFU/m^3 (Intermediate) in Phase 3 (Table 3).

Another pertinent example is with the Reading room located on the second level, where 996 CFU/m^3 (High) and 830 CFU/m^3 (High) were seen for Phase 1 and 2 respectively, and only 166 CFU/m^3 (Intermediate) in Phase 3. For a few areas sampled, there was hardly a deviation in the bacterial load between the three phases, for example, Science and Technology A, located on the top level. For CRL, two additional areas were swabbed for Phase 2, and therefore a higher bacterial load was noted (2,072 CFU/m^3) than in Phase 1 (830 CFU/m^3). The bacterial load greatly declined in Phase 3 (166CFU/m^3) (Table 3).

Table 2. Tests of normality for bacterial load of the indoor air in the library

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	Df	Sig.
CFU/m^3	0.185	39	0.002	0.891	39	0.001

a - Lilliefors Significance Correction

Table 3. Bacterial load (CFU/m^3) and their classification according to the SSEC for non industrial premises

Level	Area	Phase 1		Phase 2		Phase 3	
		CFU/m^3	Classif.	CFU/ m^3	Classif.	CFU/ m^3	Classif.
Top level	CRL A	83	Low	83	Low	166	Inter
	CRL B	332	Inter	83	Low	0	NG
	CRL C	332	Inter	166	Inter	0	NG
	CRL D	83	Low	83	Low	0	NG
	CRL X	-	-	1,328	High	-	-
	CRL Y	-	-	332	Inter	-	-
	Science &Tech A	913	High	664	High	747	High
	Science &Tech B	996	High	747	High	581	High
	Total	2,739		3,486		1,494	
Second	Law & Social sci	83	Low	83	Low	83	Low
level	Office complex	1,826	High	830	High	664	High
	Circulation	830	High	249	Inter	498	Inter
	Reading room	996	High	830	High	166	Inter
	Total	3,735		1,992		1,411	
Ground	Acquisition	1,245	High	996	High	498	Inter
level	Common room	*3,071*	Very High	913	High	*	*
	Information Desk	1,494	High	166	Inter	581	High
	Reading room	830	Inter	83	Low	664	High
	Total	6,640		2,158		1,743	
Overall Total per phase		13,114		7,636		4,648	
No of areas with high CFU/m^3			8 (57%)		7(48%)		5 (36%)
No of areas with very high CFU/m^3			1 (2%)		0		0
Overall Total per floor		Ground floor-10,540		Middle floor-7,138		Top-7,719	

- Not done, *Discarded due to water contamination, NG - No Growth

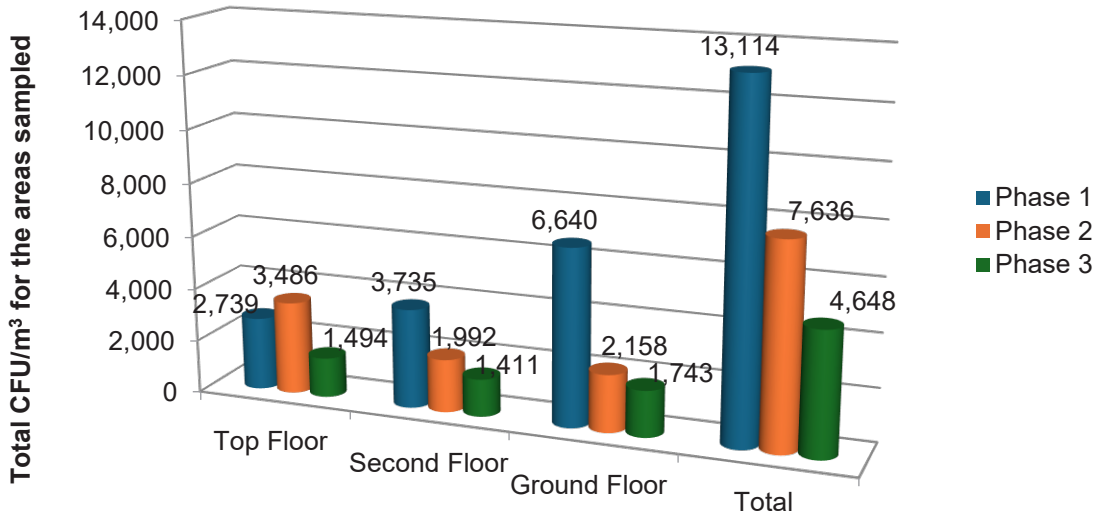

Fig. 1. The total bacterial load for the area sampled

Table 4. Bacterial load (CFU/m^3) above the normal level based on the ACGIH

Levels	Phase 1		Phase 2		Phase 3		Total no. of areas sampled	Total no. of areas with ≥ 500 CFU/ m^3 (%)
	No. of areas sampled	No of areas with ≥ 500 CFU/ m^3 (%)	No. of areas sampled	No of areas with ≥ 500 CFU/ m^3 (%)	No. of areas sampled	No of areas with ≥ 500 CFU/ m^3 (%)		
Top Floor	6	2 (33)	8	3 (38)	6	2 (33)	20	7 (35)
Middle Floor	4	3 (75)	4	2 (50)	4	1 (25)	12	6 (50)
Ground Floor	4	4 (100)	4	2 (50)	3	2 (67)	12	8 (67)
Total	14	9 (66)	16	7 (44)	13	5 (39)	43	21 (49)

NB- one sample in phase 3 AQT was contaminated and discarded

Table 5. Kruskal-Wallis H test

	Statistic	Df	Sig.
Levels	5.324	2	0.070
Phases	5.864	2	0.053

The bacterial load varied for the different floors ranging from 1,497 to 6,640 CFU/m^3. The ground floor had the highest microbial load for Phase 1 (6,640 CFU/m^3) and Phase 3 (1,743 CFU/m^3), while the top floor had the highest for Phase 2 (3,486 CFU/m^3). Overall, the ground floor had the heaviest microbial contamination (10,541 CFU/m^3), followed by the top floor (7,719 CFU/m^3), and then the middle floor (7,138 CFU/m^3). For all the floors, more than 1000 CFU/m^3 was observed (Table 3).

Table 3 shows that based on the SSEC classification, Phase 1 had the most samples (57%) that were classified as high followed by phase 2 (44%) and Phase 3 (36%). The common room located on the ground floor was the only sample classified as very high in Phase 1, while none was noted for Phases 2 and 3.

Table 4 showed that 53% of the samples collected from the three phases of the air quality tests were above the normal air quality threshold, that is, above 500 CFU/m^3. Phase 1 had the most samples (65%) above 500 CFU/m^3, followed by Phase 2 (44%) and Phase 3 (36%). In terms of the levels, the ground floor had the most samples (67%) above 500 CFU/m^3, followed by the middle floor (50%) and the top floor (35%).

Statistical analysis

Table 5 shows the results of the Kruskal-Wallis H test used to determine statistically significant differences between the phases of the AQT and the levels in the library. The P-value was greater 0.05 for both the phases of the AQT and the levels in the library.

Microbial load for CRL

Fig. 2 revealed that CRL on the top floor of the library had a total microbial load that ranged from 498- 5149 CFU/m^3 for the areas sampled for the three phases of the AQT. The bacterial load ranged from 83-1328 CFU/m^3, while the fungal load ranged from 83- 2,739 CFU/m^3.

Bacterial load for CRL

The total bacterial load for Phase 2 (2,158 CFU/m^3) was higher than that of Phase 1 (830 CFU/m^3) and Phase 3 (166 CFU/m^3). Two additional areas were swabbed for Phase 2, and therefore a higher bacterial load was noted. However, the bacterial load for Phase 2 (498 CFU/m^3) would have remained the highest even if those two areas were not included (Table 3, Fig.2).

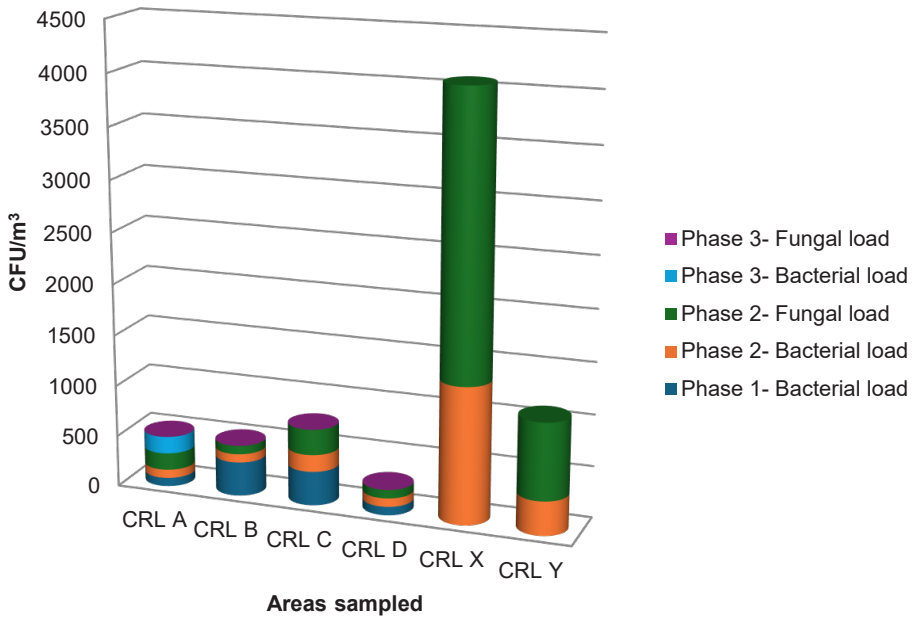

Fig. 2. CRL on the top floor of the library for the areas sampled for the three phases of the AQT

Table 6. Fungal load (CFU/m^3) & classification according to the SSEC for non industrial premises for CRL

Level	Area	Phase 2		Phase 3
		CFU/ m^3	Rate	CFU/ m^3
Top floor	CRL A	166	Intermediate	0
	CRL B	83	Low	0
	CRL C	249	Intermediate	0
	CRL D	83	Low	0
	CRL X	2,739	Very high	-
	CRL Y	747	High	-
Total		4,067	Very high	0
No of areas with high fungal load			1 (17%)	
No of areas with very high fungal load			1 (17%)	

Fungal load of the indoor air in the library

The total fungal load for Phase 2 (4,067 CFU/m^3) was higher than that of Phase 3 (0 CFU/m^3) (Table 6). Table 7 revealed that 33% of the samples collected from CRL in Phase 2 of this study had more than 500 CFU/m^3, while no growth was observed from the samples collected in Phase 3. Overall, 20% of the samples collected in Phases 2 and 3 for CRL had more than 500 CFU/m^3. More than 1000 CFU/m^3 was observed for Phase 2 (Table 7). Growth was seen for all the areas sampled in Phase 2 while no growth was seen for all the samples collected in Phase 3.

It is important to note that a higher fungal load (4,067 CFU/m^3) was observed when compared to the bacterial load (1,494 CFU/m^3) for Phase 2. However, a higher bacterial load (1,494 CFU/m^3) was noted when compared to the fungal load (0 CFU/m^3) for Phase 3.

Table 7. Effective and ineffective disinfectants against *Bacillus sp.* and *Salmonella sp.*

Disinfectant	Concentration	Organism	Time of Exposure (Mins)			
			2	5	10	15
Sodium	Pure	*Salmonella*	-	-	-	-
Hypochlorite		*Bacillus*	-	-	-	-
	5%	*Salmonella*	-	-	-	-
		Bacillus	+	-	-	-
	10%	*Salmonella*	-	-	-	-
		Bacillus	+	+	+	+
Clorox clean up	Pure	*Salmonella*	-	-	-	-
		Bacillus	+	+	+	-
Pine sol	Pure	*Salmonella*	-	-	-	-
		Bacillus	+	+	+	-
	5%	*Salmonella*	-	-	-	-
		Bacillus	+	+	+	+
	10%	*Salmonella*	-	-	-	-
		Bacillus	+	+	+	+
Hygenol	Pure	*Salmonella*	-	-	-	-
		Bacillus	+	+	+	+
	5%	*Salmonella*	-	-	-	-
		Bacillus	+	+	+	+
	10%	*Salmonella*	-	-	-	-
		Bacillus	+	+	+	+
Ger.sol	Pure	*Salmonella*	-	-	-	-
		Bacillus	+	+	+	+
	5%	*Salmonella*	-	-	-	-
		Bacillus	+	+	+	+
	10%	*Salmonella*	-	-	-	-
		Bacillus	+	+	+	+
Lysol	Pure	*Salmonella*	-	-	-	-
		Bacillus	+	+	+	+
	5%	*Salmonella*	-	-	-	-
		Bacillus	+	+	+	+
	10%	*Salmonella*	-	-	-	-
		Bacillus	+	+	+	+

NB: + growth = ineffective disinfectant, - no growth= effective disinfectant

- Not done

Disinfection experiment

In terms of the disinfection experiment, for pure Sodium hypochlorite (bleach) and its 5% dilution, no growth was seen for both organisms all the time except at 2 m for Bacillus. For the 10% dilution, growth was seen for Bacillus all of the time, but not for Salmonella. For pure Clorox Clean Up and Pine Sol, growth was seen for Bacillus for up to 10 m. Growth was seen for Bacillus at all the different times for the two dilutions of Pine-sol, pure Hygenol, Lysol, and their dilutions (Table 6).

The potential risk of disease transmission by bioaerosols from an indoor environment cannot be over-emphasized. Although much study has been done in this area, it remains a prominent source of respiratory diseases. The total bacterial load of the air in UG's Main Library was higher in phases one and two when compared to Phase 3. Furthermore, based on the SSEC classification, the bacterial air quality of UG's Main Library ranged from Low to Very high with high being more prevalent for all three phases; however the number of samples that were considered high decreased from Phase 1 to 3. Our study highlighted that several samples from all three phases were above the normal air quality threshold according to ACGIH with samples from Phase 1 being more prevalent. However, the number of samples that were above the normal threshold decreased from Phase 1 to 3. This study reveals that vast numbers of bacteria are aerosolized affecting the quality of air in the main library. However, the count seems to decline after the disinfection intervention to some extent.

The bacterial load for our study ranged between 2,739- 6,640 CFU/m^3 for Phase 1, 1,992- 3,486 CFU/m^3 for Phase 2, and 1,411- 1,743 CFU/m^3 for Phase 3. Phase 1 and 2 bacterial loads in the indoor environment of UG main library were higher than in a similar study done by Jimma University, Ethiopia, where the bacterial load ranged between 367-2595 CFU/m^3 [9], a study done in Central Library of the University of Yaoundé I, Cameroon; where the bacterial load ranged between 747 and 2324 CFU/m^3 [19]; and a study done in a college campus in Bengaluru, India, where 924 CFU/m^3 were observed in the library [5] . The results from our study were lower than a similar study done in some offices at the University of Ilorin, Nigeria, where the bacterial load ranged from 0 to 24,735 CFU/m^3 [20].

It was obvious from this study that all the areas sampled in the main library were contaminated but in varying degrees. For Phase 1, the level with the highest contamination was the ground level (6,640 CFU/m^3). This finding was above the WHO exposure guidelines for indoor environments. Lower results were noted for a study done in the Central Library of the University of Yaoundé I, where the ground level had 1,420 CFU/m^3 [19].

Our findings suggest that microbial contamination of the air decreases as we ascend from floor to floor. Furthermore, foot traffic results showed that the lower level was utilized more than the upper levels; and library users were frequently present when Phase 1 AQT was carried out. Research has shown that human activity influences microbial load indoors [12, 21]. In addition, we postulate that microbes may have settled on books and other objects; thereby decreasing the air count for the other levels.

For Phase 2, a lower bacterial load was noted for the ground floor. We assume that this was because at the time of sample collection, the library was closed and so there was less human activity. However, the bacterial load was still above the WHO exposure guidelines for indoor environments.

Our results indicated that CRL is heavily contaminated with microbes, more fungi than bacteria. Studies have shown that fungi are likely to be present seven times more than bacteria in indoor environments. Based on our observation, CRL had a buildup of moisture which probably favored the development of fungi especially

molds. The World Health Organisation (WHO) indicated that dampness contributes to the biological contaminants of indoor air [10]. The fungal load of CRL was found to be in the range of 83-2739 CFU/m^3. Lower results (±31–397 CFU/m^3) were found in a study done in public buildings in Egypt including libraries [22]. Although fungi were more dominant than bacteria, no fungal growth was observed after the disinfection intervention. The rehabilitation of CRL to eliminate the buildup of moisture may have contributed to the low fungal count in Phase 3.

While the bacterial load differs across areas on the different floors and phases of AQT, statistical analysis revealed that those differences are not statistically significant at the 0.05 alpha level. Therefore, we accept the null hypothesis that the distribution of bacterial loads is the same across the different phases of the AQT and levels of the library. However, it must be noted that there was not enough evidence to conclude a statistically significant difference in bacterial loads among the phases and the floors. While the p-value is not below 0.05, suggesting non-significant results at the 0.05 alpha level, it still indicates a trend that might merit further exploration, potentially increasing sample size for better insight.

The library is greatly contaminated with microorganisms that are potentially hazardous to dwellers. We believe that the microbial load from our study was favored by environmental conditions like poor ventilation, moist conditions, and high humidity which supported the growth and multiplication of microbes.

The most effective and economical disinfectants against *Salmonella* and *Bacillus* were Bleach and Clorox Cleanup. This study revealed that there was a significant drop in the level of microbial contamination in the main library after the disinfection intervention was carried out. There was no microbial growth in CRL and less bacterial growth in most of the other areas. This means that the disinfection regimen worked against the bacteria. However, since growth was still noted for several areas, we recommend further cleaning and disinfection. Of note, even though there was a reduction in microbial load as well as an absence of microbial growth in some cases, it does not mean that the library will always remain safe. Research has suggested that in tropical climates, the absence of a climatic control system could lead to a periodic reappearance of molds in libraries [14].

This study was useful to UG's administration as they upgraded the library and sought to create a safe environment for students and staff. Our study was limited because rehabilitation and fumigation were ongoing during the year and may have affected our findings. However, our study clearly showed that the disinfection protocol contributed to the reduction of the overall microbial load.

Conclusion

The library is an essential indoor facility where many students and staff spend their time daily. As such, the air quality should be optimum concerning its microbial load. We concluded that a high microbial load was found in our study prior to the disinfection intervention which was considerably diminished after the intervention. Therefore, the cleaning regimen we developed should be implemented as part of the library's cleaning protocol. The importance of continuous cleaning and maintenance cannot be overemphasized and as such we implore that sanitization and fumigation be done as often as possible to keep the library safe from microbial contaminants. We also recommend that further studies be done using settle plates and surface sampling, periodically to determine the true representation of the microbial load in the library. However, more areas in the library need to be investigated to determine statistically significant results. Moreover, a study can be done to identify and quantify the specific microbial species present in the library.

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Competing interests

The authors declare they have no conflicts of interest or competing interests.

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Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/ or falsification, double publication and/ or submission, redundancy, etc) have been completely ob-served by the authors.

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