Microbial Indoor Air Quality and Associated Factors in Jimma Town Prison Administration, Southwestern Ethiopia

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ABSTRACT: Indoor air quality determines the well-being of occupants. It has been linked to sick building syndrome and building-related diseases which lead to many socio-economic problems including reduced productivity and impaired learning. Indoor air quality problem is more serious for prisoners, due to their confinement and exposure condition. However, it has not been studied in our study setting. Thus, this study aimed to determine the indoor air microbial quality and associated factors in Jimma town prison administration, Southwestern Ethiopia. A cross-sectional study design was employed in August 2021. Data on the general condition of the prison rooms and occupancy were collected by trained data collectors using an observational checklist. The microbial sample was collected using a sterilized Petri dish. A total of 19 triplicate air samples were collected using Mannitol salt agar and Sabouroad dextrose agar media for the growth of *S. aureus* and fungi respectively. Data were analyzed using SPSS version 23 and presented using tables and a graph. The effect of predictor variables on the microbial load was also analyzed by using linear regression. The finding of this study revealed that the microbial load of indoor air at Jimma town prison administration ranged from 891 to 15 439 and 315 to 3067 CFU/m^3 for *S. aureus* and fungi respectively. Both *S. aureus* and the fungal load of the indoor environment were positively affected by the temperature of the room. Whereas, the floor space per inmate affects the concentration of *S. aureus* alone. Almost all rooms of the prison administration had microbial load beyond the acceptable limit. Higher temperature, less floor space per inmate, bad floor cleanness conditions, inadequate ventilation, and dampness were contributing factors to the high load of *S. aureus* and fungus. Thus, additional rooms are required to reduce overcrowding and keep room temperature.

KEYWORDS: Prison health, inmate, microbial load, indoor air quality, ***S. aureus***, fungi

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Introduction

Indoor air quality (IAQ) usually refers to the air quality within and around buildings and structures that are other than industrial environments. These building premises include; colleges, hospitals, offices, restaurants, homes, and similar partially closed settings[1] where people stay inside more than 90% of their time.[2-5] IAQ is a major public health concern and known to affect the health, comfort, and well-being of the residents,[6] especially those individuals with comorbidity from respiratory and allergic problems and who have suppressed immunity level.[5] Pollution of the interior environment has been linked to many human health problems. Sick building syndrome and building-related diseases are the 2 major categories that can lead to many other socio-economic problems like reduced productivity and impaired learning in schools.[7]

Since indoor air pollution is among the leading risk factors for diseases and death,[1] globally 3.8 million deaths were attributed to it in the year 2016. Of this, more than 90% of air pollution-related deaths occur in economically compromised nations constituting African countries.[8,9] This is an alarm for special attention and particular concern to those who necessarily spend the majority of their time indoors like prisoners.[7]

Based on the onset of the problem, we can classify the health effects of indoor air pollution as acute and chronic cases. Some illness occurs shortly after a one-time or acute exposure to the pollutants. The eye, nose and throat irritation, headaches, dizziness and fatigue are categorized under this group and are treatable. Sometimes the treatment is simply avoiding the person's exposure to the source of the pollution and concentrating on the contributing factors if they are identified. Soon after such exposure to these pollutants, symptoms of some diseases[2] such as asthma can also be occurred, aggravate or worsen.[6] Another health problem of indoor air pollution is chronic health cases that could happen after a long period or repeated exposure. These health defects include some respiratory diseases, heart disease, and cancer. They can be severely enfeebling or leads to life-threatening consequences unless preventive measures are taken. This can be achieved by improving the IAQ, even though the signs and symptoms of the cases are not noticeable.[1,6]

Many physical and environmental factors influence IAQ. These factors affect the fresh air coming into the building and include human activities, poor ventilation (lack of outside air or poor indoor air circulation), fluctuation in temperature and humidity and other activities in or around the interior environment of the building premises. The entry of contaminants from the outdoor environment like dust from different activities and chemical emissions (construction or renovation, cleaning supplies, pesticides, etc.) may also contribute to poor IAQ.[3,5,7,10] Bacteria, fungi, and viruses, collectively microorganisms[11,12] are

the key elements of indoor air pollutants and contribute about 5% to 34% to indoor air pollution health problems.[3,5,8,9] Particular activities like talking, sneezing, coughing, walking, and washing can majorly release these airborne biological contaminants and form air suspensions that increase exposure for the inmates.[13-15] Indoor air quality problems for prisoners can be even more serious, due to their confinement and exposure level, duration, and frequency.[7]

So far different scholars emphasized studying the indoor air microbial quality condition around different building premises like public libraries, health care facilities, schools, university dormitories, and others.[8,9,11,16-19] However, there are limited studies conducted that assess the prison IAQ situation, especially in our present study area. Furthermore, for better and timely control and prevention of short and long-term exposure of inmates to biological hazards that might pose the aforementioned human health risks, continuous measurement along with the assessment of associated factors is indispensable. Thus, this study aimed to assess the microbial (*S. aureus* and fungal) load of indoor air in Jimma town prison administration with associated factors and to give insight into how prison inmates are exposed to biological air contaminants.

Materials and Methods

Study design and setting

A cross-sectional study was conducted on prison administration in Jimma town, Southwest Ethiopia in August 2021. The area locates 345 km southwest of the capital, Addis Ababa and lies between an elevation of 1740 and 1760 m above sea level. The average maximum and minimum temperatures of the area are 25 to 30°C and 7 to 20°C respectively. The area receives annual precipitation ranging from 1200 to 2000 mm[16] Southwest Ethiopia is a forested region of the country and known for its coffee plantation.[20] The study is conducted specifically in Jimma town prison administration, found in Jimma town. The prison has a total of 19 rooms for the prisoners, 16 rooms (13 for adults 3 for young inmates) for males and the remaining 3 for females. It has a total of 1984 prisoners during the study, of this 87 being females and 1897 males.

Sample size and sampling

All 19 prison rooms were occupied during sampling, thus included and sampled in this study. *S. aureus* and fungal sampling were conducted by passive air sampling technique using a settle plate method following standard procedures as described by Hayle-eyesus et al.[16] *S. aureus* is selected based on (1) its high salt-tolerant capacity enables it to grow in dry places where the other pathogenic bacterial group cannot,[21] (2) its major source is the human carriage in an area where high occupants are found like a prison (from the occupant of nostrils, skin, etc.), and (3) its antimicrobial resistance currently more prevalent over the other bacteria groups.[22] The samples were collected using a sterilized Petri dish (9 cm diameter and an area of 63.585 cm^2) by exposure to the indoor air for all 19 rooms. In each room, triplicate samples were taken to increase the reliability and representativeness of the sample. Four negative control from 2 randomly selected rooms were also taken (2 for *S. aureus* and 2 for fungi). This makes the total plate used during the air sampling 118, of which 59 contained Mannitol salt agar (MSA) and the remaining 59 contained Sabouroad dextrose agar (SDA) for the growth of *S. aureus* and fungi respectively. Except for the negative controls (2 plates containing MSA and 2 plates containing SDA), each plate was opened and exposed during sampling by considering the human breathing zone following 1/1/1/ principle, 1 m above the floor, and 1 m away from the wall for 60 minutes. The 60 minutes' exposure time is selected because more than an hour (90 minutes) exposure makes counting difficult and may cause counting error and exposure duration of less than an hour (30 minutes) underestimate the true picture of the load. Then the plates were closed immediately after the collection of samples and taken to Jimma University Environmental Health Sciences and Technology department laboratory for incubation.

Data collection

Data on the general condition of the prison rooms and occupancy conditions were collected by trained data collectors using an observational checklist. Ventilation type of the rooms, cleanness of floor, wall, and ceilings, number of occupants per room, area of the rooms, cleanliness of the room and presence, or absence of dampness were also included in the assessment as described in Tables 2 and 3. The temperature of each room was measured using a hand-held thermometer (model-THL-210-050T).

Sample analysis and microbial enumeration

The exposed Petri dishes and controls were incubated in an inverted position at 37°C for 3 to 4 days for fungal culture plates and at 37°C for 48 hours for *S. aureus* culture plates. Thereafter, the number of colony-forming units (CFU) was counted manually using a magnifying glass. The average value of triplicate samples was computed and used for each room. Finally, it was converted to colony-forming unit per meter cubic (CFU/m^3) by using the following standard formula.

$$N = 5a \times 10^4 \left(bt\right)^{-1}.^{23,24}$$

Where N = microbial (*S. aureus* and fungal) CFU/m^3 of indoor air, a = number of colonies per Petri dish, b = Petri dish surface area (cm^2), and t = exposure time (minutes).

Data quality assurance

To keep the quality of the study, materials were cleaned and sterilized before using them, incubation time and temperature were monitored and laboratory analysis was done with

Table 1. Total count and load in colony-forming unit per cubic meter of S. aureus and fungus in the respected rooms of Jimma town prison administration, 2021 (N = 19).

ROOM NUMBER	*S. AUREUS* COUNT/PLATE	*S. AUREUS* LOAD (CFU/M³)	FUNGAL COUNT/PLATE	FUNGAL LOAD (CFU/M³)
1	780	10223	108	1415
2	520	6815	94	1232
3	552	7234	97	1271
4	586	7680	99	1297
5	1120	14679	122	1599
6	568	7444	102	1337
7	912	11953	116	1520
8	706	9253	105	1376
9	660	8650	100	1311
10	1178	15439	234	3067
11	320	4192	58	760
12	370	4849	61	799
13	981	12857	226	2962
14	282	3696	44	577
15	318	4168	52	682
16	68	891	24	315
17	74	970	30	393
18	141	1848	42	550
19	130	1704	38	498

cautions. Quality control field blanks (un-exposed media) as negative controls were also considered for randomly selected 2 rooms to check the presence of cross-contamination in sample handling.

Data analysis and presentation

Data entry was made into Microsoft excel 2016 and exported to SPSS version 23. Descriptive statistics were used for displaying, describing and summarizing the data using tables, a graph, and narration. The effect of predictor variables on the microbial load was also analyzed by using linear regression. Before including all predictor variables directly in the model, collinearity among all predictor variables was explored. This is to reduce the uncertainty of the model. Only predictor variables with variable inflation factor (VIF) < 10 (temperature and floor space per inmate) were included in the model.

Operational definition

- Microbial load: The number of microbes in CFU/m³ of Petri dish.
- Dampness: Any visible or perceived outcome of excess moisture that could lead to problems in buildings like; leakage or material degradation or microbial proliferation such as mold.
- Adequate lighting: Systems that fulfill adequate power, absence of glare, constant and uniform, where flickers are absent and that don't cause eye strain, fatigue, accidents and don't encourage dirt due to darkness.
- Good cleanness: Conditions with trash-free walkways, mopped and stainless floor, otherwise it is bad.
- Adequate ventilation: If there is an open window that covers at least 10% of the room floor space, otherwise considered inadequate.

Results

Microbial load

The concentration of *S. aureus* and fungus in Jimma town prison administration jail rooms was expressed in colony-forming unit per plate and colony-forming unit per volume of air as depicted in Table 1.

The general condition of the rooms

As depicted in Table 2, the majority of the rooms had stone walls, stone floors, and wood ceilings. The cleanness condition

Table 2. Frequency distribution of room condition variables in Jimma town prison administration, 2021 (N = 19).

VARIABLE (PRISON HOUSE)	CATEGORY	FREQUENCY	PERCENT
Wall type	Mud	2	10.5
	Stone	17	89.5
Floor-type	Mud	2	10.5
	Stone	14	73.7
	Tiles	3	15.8
Ceiling type	Cloth	2	10.5
	Wood	17	89.5
Cleanness condition of the floor	Bad	15	78.9
	Good	4	21.1
Condition of ventilation	Adequate	9	47.4
	Inadequate	10	52.6
Lighting condition	Adequate	7	36.8
	Inadequate	12	63.2
Presence of dampness	Yes	15	78.95
	No	4	21.05

of the floor was found to be bad; the floor is made of stone not smooth and difficult to clean, again with visible dust accumulation. The practice of cleaning rooms is only with water twice a week. The type of floor sweeping is a dry method (not wet). About 63% of the rooms had inadequate lighting.

Our findings showed the microbial load in the indoor air at Jimma town prison administration, ranged from 891 to 15 439 and 315 to 3067 CFU/m^3 for *S. aureus* and fungi respectively (Table 3).

Relation among the variables

The result showed that the independent variables; the temperature of the room, area of the room, floor space per inmate, and number of occupants were significantly correlated positively or negatively with each other ($P < .05$) (Table 4).

The scatter plots of *S. aureus* versus fungi concentration showed a strong positive linear relationship (P-value $< .001$) with a regression coefficient ($R^2 = .799$) (Figure 1).

The microbial load of the indoor air and predicting variables

In this regard, only 2 variables out of 4 were included (number of occupants, area of room, floor space per inmate, and temperature) in the regression model. Tables 5 and 6 showed the effect of predicting variables on microbial load. There was an increase in *S. aureus* load in CFU/m^3 with a decrease in floor space per inmate (P-value .032) but it was not significant for the fungal load. However, both *S. aureus* and the fungal load of the indoor air increase with an increase in the temperature of the room significantly with a P-value of .007 and .019 respectively.

Discussion

Information on indoor air microbial load along with the associated factors is important to reach the root causes of these biological hazards, anticipate their health effects and provide recommendations for IAQ control and standard-setting accordingly. Thereby enabling us at the end of the day to improve the health of our community.[25]

Our findings revealed the concentrations of *S. aureus* in the indoor environment of Jimma town prison administration ranged between 891 and 15 439 CFU/m^3 with a mean value of 7081 CFU/m^3. There is no consistent or uniform national and international standard on the concentration of bacteria in CFU/m^3 for the non-industrial indoor environment.[8] However, many scholars considered the WHO expert group's biological contaminants health risk assessment work which was conducted between 2000 and 2003.[8,11,16,17,26,27] Relying on that basis, the mean concentration of *S. aureus* in Jimma town prison administration jail rooms exceeded the maximum acceptable limit which is 1000 CFU/m^3.[28]

When we compare it with other study findings, our result is in contrast with the study conducted at Jimma university student dormitories on the bio-aerosol contamination of indoor air in which the mean bacterial load was 1652 CFU/m^3 and ranged from 511 to 4010 CFU/m^3.[16] A similar study was done in Jimma University main campus with similar methodology but different study setting (library) by Hayle-eyesus and Melaku. The mean value of bacterial load in that library was lower than the present study which was 1476 CFU/m^3 and ranged between 367 and 2595 CFU/m^3.[11] This difference might be explained by the difference in the number of occupants at the 2 buildings settings and sampling exposure time. Similarly, our result disagrees with those of Larrey et al, a study conducted in a teaching hospital in Ghana in which the bacterial load ranged from 492 to 5395 CFU/m^3.[4] The variation might be excused by the difference in study season and setting (hospital versus prison). In the former work, both dry and wet seasons were considered, unlike in the present study. Besides, our finding is comparable to the result recorded by Fekadu and Getachewu[17] at Jimma University Specialized Hospital (the current Jimma University medical center), which is in the range of 3106 and 9733 CFU/m^3. On the other hand, the finding of another study which was conducted in Gonder city, Ethiopia, on public primary schools revealed that the maximum bacterial concentration was much higher than our findings which is

Table 3. The minimum, maximum, mean, and standard deviation of some determining room conditions and microbial load of indoor air in Jimma town prison administration, 2021 (N = 19).

VARIABLE	MINIMUM	MAXIMUM	MEAN	STANDARD DEVIATION
Number of open windows per room during the study	1.0	5.0	4.263	4.2275
Number of occupants per room	10	155	99.05	57.814
Area of the room (m^2)	24	100	79.16	29.540
Floor space per inmate (m^2/person)	0.65	2.4	1.06	0.53688
Temperature (°C) of the room	27.5	32.5	29.779	1.6054
S. aureus count/plate	68	1178	540.32	344.778
S. aureus load (CFU/m^3)	891	15439	7081.32	4518.784
Fungal count/plate	24	234	92.21	57.815
Fungal load (CFU/m^3)	315	3067	1084.21	680.064

Table 4. Shows the correlation among the room condition variables in Jimma town prison administration, 2021 (N = 19).

	TEMPERATURE (°C)	FLOOR SPACE PER INMATE (M^2/PERSON)	AREA OF THE ROOM (M^2)	NUMBER OF OCCUPANTS
Temperature (°C)				
Pearson correlation	1	–.547*	.535*	.626**
Sig.		.015	.018	.004
Floor space per inmate (m^2/person)				
Pearson correlation	–.547*	1	–.765**	–.895**
Sig.	.015		.000	.000
Area of the room (m^2)				
Pearson correlation	.535*	–.765**	1	.922**
Sig.	.018	.000		.000
Number of occupant				
Pearson correlation	.626**	–.895**	.922**	1
Sig.	.004	.000	.000	

*Correlation is significant at the .05 level. **Correlation is significant at the .01 level.

23 504 CFU/m^3.[9] This variation might be best explained by the 2 study area climatic condition differences and study setting variation. The physical environment, the inhabitant's characteristics and the activities within prisons and schools are different. However, in this study, the minimum value (208 CFU/m^3)[9] is lower than our finding. This is because school rooms are less or not occupied at all in the early morning (around 6:30 AM) when the sample was taken.

Based on our findings, the fungal load of the jail rooms ranged from 315 to 3067 CFU/m^3 with a mean value of 1084 CFU/m^3. Again this value is beyond the WHO indoor air quality standard set by the institution's working group similar to the bacterial load record. Besides, our finding is in agreement with those of Fekadu and Getachewu,[17] in which the maximum and minimum fungal load in CFU/m^3 were 524 and 1992 with a mean value of 1087. However, it is in contrast with the work of Hayle-eyesus et al[16] in which the average maximum and minimum fungal load in CFU/m^3 were 630 and 6485 with a mean value of 2096.[16] This variation might be due to the difference in the study setting (the former conducted on University dormitory and the timely building conditions and environmental factors) and sampling exposure time. Similarly,

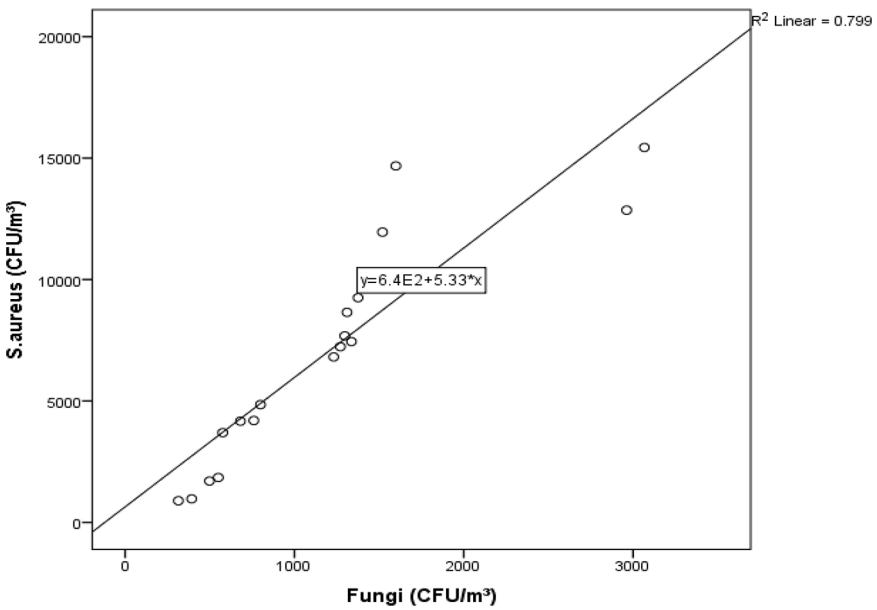

Figure 1. Scatter plots of *S. aureus* versus fungi concentration in Jimma town prison administration, 2021 (N = 19).

Table 5. Shows the linear regressions using indoor total *S. aureus* load as a dependent variable.

MODEL		UNSTANDARDIZED COEFFICIENTS		STANDARDIZED COEFFICIENTS	*T*	SIG.
		B	STANDARD ERROR	BETA		
1	(Constant)	−33356.693	15276.048		−2.184	.044
	Floor space per inmate (m²/person)	−3393.183	1442.784	−.403	−2.352	.032*
	Temperature (°C)	1479.278	482.500	.526	3.066	.007*

*Correlation is significant at the .05 level.

Table 6. Indicates the linear regressions using indoor total Fungal load as a dependent variable.

MODEL		UNSTANDARDIZED COEFFICIENTS		STANDARDIZED COEFFICIENTS	*T*	SIG.
		B	STANDARD ERROR	BETA		
1	(Constant)	−5186.607	2710.980		−1.913	.074
	Floor space per inmate (m²/person)	−378.221	256.045	−.299	−1.477	.159
	Temperature (°C)	224.104	85.627	.529	2.617	.019*

*Correlation is significant at the .05 level.

based on the study conducted on the microbial contamination in the indoor air of private maternity homes in Moga, Punjab, the fungal load record in CFU/m³ ranged between 79 and 826[29] which is lower than our result. This difference might be attributed to better quality management in private maternity homes over public prisons. However, our result is in agreement with those of Larrey et al, in which the bacterial load ranged from 278 to 2022 CFU/m³.[4] In general, almost all rooms (89.5%) of the Jimma town prison administration have bacterial and fungal load above the acceptable limit.[28]

The maximum *S. aureus*, as well as the fungal load, were detected in the same room (Table 3) which implies the determining factors for both inhabitants of the indoor environment could be similar. As is presented by the regression model (Tables 5 and 6), both *S. aureus* and the fungal load of the indoor air positively associated with the temperature of the

room significantly ($P = .007$ and $P = .019$ respectively). This can be explained by the fact that the rise in temperature triggers the activities and movement of microorganisms from building and human body parts which leads to the suspension of these bioaerosols. A prison should have a day temperature of 20 to 22.2°C[30] but in our result, it ranged from 27.5 to 32.5°C.

The floor space per inmate (m^2/person) significantly affects the concentration of *S. aureus* negatively ($P = .032$). This is due to the bacterial load being attributed to the number of occupants as a human is a reservoir of *S. aureus*[31] when they are released by different occasional activities like sneezing, coughing, and talking.[12,13] However, the number of occupants by itself cannot affect microbial load in the indoor environment. Rather the crowding index matter. Even though the number of occupants or inmates is too high, as far as the room space is sufficient enough to disperse the interior air, one cannot detect a high load of these biological contaminants. The floor space per inmate (m^2/person) in the current studied prison (maximum value of 2.4 m^2/inmate) did not match the standard, 5 m^2/inmate.[30] Despite that, in our result, the fungal load is not significantly affected by this factor. Contrary to *S. aureus*, the growth of fungi is mostly associated with the presence of materials (like; ceiling, floor, and wall materials) that provide carbon sources and adequate moisture.[32,33] The high fungal load, in the present study might be linked with the indoor air dampness[1,15] where nearly 79% of the building's rooms had visible dampness problems. The high microbial load can also be attributed to the poor cleanness condition of the floor where most (15 out of 19) of the rooms had such problems in the present study.

Conclusion

Almost all rooms of Jimma town prison administration have a high microbial load which is beyond the WHO acceptable limit. The higher temperature of rooms, less floor space per inmate, bad floor cleanness conditions, dampness, and inadequate ventilation were the contributing factors to the high load of *S. aureus* and fungus. This could endanger the health of the inmates by exposing them to different airborne health problems. Based on our findings, the following measures are strongly suggested to Jimma town prison administration and other responsible bodies: (1) Construction of additional rooms for inmates to reduce overcrowding in rooms thereby keeping room temperature. (2) Regular and appropriate cleaning should be practised to the improvement of cleanliness of the floor and the rooms. (3) We also recommend further study to be conducted on the other pathogenic bacterial species and fungal species along with some other factors which are not considered in this study.

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Author Contributions

MA conceived and designed the study. HA collected the data, MA and HA analyzed and interpreted the data, and prepared and wrote the manuscript. GH was involved in the revision of the manuscript. The final manuscript was critically reviewed and approved by all authors.

Availability of Data and Materials

Data will be available upon request, by the corresponding author.

Ethical Consideration

Ethical clearance was obtained from the ethical review board, the institution of Health Science, Jimma University.

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