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Article

Second-Hand Tobacco Smoke Exposure: Results from a Particulate Matter ($PM_{2.5}$) Measurement at Hospitality Venues in Addis Ababa, Ethiopia

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Abstract: Introduction: In Ethiopia, a comprehensive smoke-free law, which bans smoking in all public areas, has been implemented since 2019. This study aimed to evaluate compliance with these laws by measuring the air quality and conducting covert observations at 154 hospitality venues (HVs) in Addis Ababa. **Methods:** Indoor air quality was measured using Dylos air quality monitors during peak hours of the venues, with concentrations of particulate matter <2.5 microns in diameter ($PM_{2.5}$) used as a marker of second-hand tobacco smoke. A standardized checklist was used to assess compliance with smoke-free laws during the same peak hours. The average $PM_{2.5}$ concentrations were classified as good, moderate, unhealthy for sensitive groups, unhealthy for all, or hazardous using the World Health Organization's (WHO) standard air quality index breakpoints. **Results:** Only 23.6% of the venues complied with all smoke-free laws indicators. Additionally, cigarette and shisha smoking were observed at the HVs. Overall, 63.9% (95% confidence interval:56-72%) of the HVs had $PM_{2.5}$ concentrations greater than 15 μg/m3. The presence of more than one cigarette smoker in the venue, observing shisha equipment in the indoor space, and the sale of tobacco products in the indoor space were significantly associated with higher median $PM_{2.5}$ concentration levels ($p< 0.005$). Hazardous level of $PM_{2.5}$ concentration, 100 times overfold than the WHO standard was recorded from HVs where several people were smoking shisha and cigarette. **Conclusions**: Most HVs had $PM_{2.5}$, which exceeded the WHO average air quality standard. Stricter enforcement of smoke-free laws is necessary, particularly for bars, nightclubs/lounges.

Keywords: Secondhand smoke exposure, $PM_{2.5}$, hospitality venues

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1. Background

Secondhand tobacco smoke (SHS) exposes individuals to toxic and carcinogenic components [1]. Particulate matter ($PM_{2.5}$) is a mixture of solid and liquid particles with a diameter of <2.5 μm, that serves as a biomarker for SHS exposure in both indoor and outdoor public places [1-5]. Even short-term exposure to these particles has been linked to increased mortality due to cardiovascular, respiratory, and cerebrovascular diseases [4,6]. Studies measuring airborne nicotine concentrations [7] and $PM_{2.5}$ concentrations [8] have reported higher SHS concentrations in hospitality venues (HVs) than in other public places. Tobacco smoking is the main source of $PM_{2.5}$ pollution in indoor spaces, producing far more fine particles than other sources [5]. In Scotland, a study reported a significant reduction in $PM_{2.5}$ concentration following the ban on smoking in pubs [9].

Article 8 of the World Health Organization (WHO) Framework Convention on Tobacco Control (FCTC) calls upon all parties to implement measures to safeguard the public from SHS exposure in indoor public spaces [10]. Ethiopia enacted a comprehensive tobacco control law in 2019 (Proclamation 1112/2019) [11] to create smoke-free public spaces, including HVs. The aim of such laws is to reduce SHS exposure and consequently protect the health of nonsmokers. Studies have shown that comprehensive smoke-free laws can effectively reduce SHS in public venues, increase the demand for smoking cessation, and decrease smoking among young people [12, 13].

Studies conducted in African countries have shown a lack of knowledge and low compliance with smoke-free policies in various hospitality venues such as hotels, bars, nightclubs, pubs, and restaurants [14, 15]. A 2016 survey in Ethiopia revealed that 60% of adults were exposed to secondhand smoke in bars and nightclubs, and 31% in restaurants [16]. To evaluate the effective implementation of these laws, it is crucial to conduct observations and measure air quality in these establishments. In this study, the researchers used a low-cost air quality monitor, the Dylos1700, to measure mass concentrations of PM with sizes ranging from 0.5 μm to 2.5 μm in HVs in Addis Ababa [5, 17]. The primary objective of this study was to measure the mass concentration of particles within this range, which is indicative of exposure to secondhand smoke. The findings of this study will be useful for decision-making regarding the implementation and enforcement of smoke-free laws in these venues in Ethiopia.

2. Methods

2.1. Study area and design

This cross-sectional study was conducted in Addis Ababa, Ethiopia as part of a larger national study assessing compliance with smoke-free laws. The city administration consists of 11 sub-cities [18] housing nearly five million people [19]. Each sub-city is further divided into woredas, which represent the lowest public administration structure in Ethiopia.

2.1 Sample size estimation

The national study had a total sample size of 1300 HVs across 10 major cities in Ethiopia. This sample size was based on a similar study conducted in Uganda, which found that 82% of the surveyed HVs complied with 'no active smoking' in venues [20], with a 95% confidence level, 3% margin of error, a design effect of two, and a 5% non-response rate. A total of 285 HVs were allocated to Addis Ababa and 154 HVs were selected for PM measurements. Most studies recommend measuring $PM_{2.5}$ levels in an area or city between 20 and 100 HVs, with various types of venues, such as bars, hotels, restaurants, cafés, and nightclubs [21].

2.3. Sampling techniques

Six-sub cities in Addis Ababa were selected for this study based on the high number of registered HVs: Addis Ketema, Arada, Bole, Kirkos, Lideta, and Nefas-Silk-Lafto. Within each sub-city, the woreda with the highest number of HVs was chosen in consultation with the Tobacco Control Law Enforcement Team of the Addis Ababa, Food, Medicine, and Healthcare Administration and Control Authority (FMHACA). The list of HVs at the sub-city's Bureau of Trade and the Woreda Office was incomplete and inconsistent, so the selection process involved dividing the woreda into clusters and selecting 4-6 clusters with a high density of HVs and multiple streets, following WHO's recommended approach for this type of study [22].

We listed the number and types of HVs in the selected clusters by walking through each neighborhood. After compiling the names and categorizing the HVs in the delineated clusters, we allocated a sample size proportional to the various types of HVs (restaurants, cafés, hotels, groceries, bars, and nightclubs/lounges). A systematic random sampling approach was employed to select a subsample of 154 HVs for the air quality measurements.

Data collection was carried out for 10 days using a standardized checklist that was informed by the 'How-to-Guide for Conducting Compliance Studies' for the smoke-free law [23] and the provisions of the Ethiopian Tobacco Control Proclamation (1112/2019) [11]. The checklist was translated into the Amharic and back translated into English to ensure consistency. Covert observation of compliance with smoke-free laws in all study hospitality venues (HVs) was conducted using three pairs of trained data collectors and one supervisor using Open Data Kit (ODK) (https://opendatakit.org) enabled smartphones. Electronic data were uploaded to a local server at the Addis Ababa University (AAU).

2.4 $PM_{2.5}$ measurement

At the beginning of each data collection period, Dylos DC1700 was turned on to start recording the outside $PM_{2.5}$ for a minimum of 30 min once a day. The device was left in operation, and particle concentrations were continuously measured until the end of the collection period. The purpose of outside air sampling was to establish comparative data for indoor air samples obtained on the same day [21]. Following the measurement of outdoor air quality, the data collectors entered the selected HV and identified the central location within the venue to assess the indoor $PM_{2.5}$. They placed Dylos DC1700 equipment away from open doors, windows, mechanical ventilation, open flames, or other sources of SHS to minimize external interference. To ensure accurate indoor measurements, the bag containing the monitor was placed at table or chair level, at least 1 m from any smoker, and beverages were ordered for the data collectors. Indoor measurements were performed for a minimum of 30 min.

After each period, Dylos DC1700 was turned off, and the data were downloaded to a PC using Dylos Logger software. The start and end times for each venue's $PM_{2.5}$ recording were also recorded, along with the type of venue, entrance and exit times, room size, number of people present, number of people using tobacco products, presence of mechanical ventilation, presence of any source of smoke, and whether doors/windows were open. The peak hours for HVs were considered for observing and measuring $PM_{2.5}$ levels, between 18:00 and 24:00 hour East Africa Time (EAT).

2.5 Data analysis

Data cleaning and analysis were performed using SPSS version 26 and STATA version 14. Descriptive statistics, such as frequencies, proportions, mean, median, interquartile range (IQR), and standard deviations (SDs), were used to summarize the data. Seven smoke-free law specific indicators were used to assess indoor space compliance, including the absence of smoking, ashtrays, lighters, shisha equipment, and tobacco products within 10 m of any door, window, or air intake mechanism.

For each HV type, the overall average compliance with the smoke-free law was determined using a method employed in previous studies [17, 23, 24], where the compliance percentages for each smoke-free law indicator were added and the sum was divided by the total number of indicators. Differences between groups were assessed using the t-test, with the significance level set at $P<0.05$ for statistical significance.

The Dylos DC1700 measures, the particle number concentrations up to 0.5 μm (small particles) and 2.5 μm and above (large particles) in 0.01 cubic foot of air for each minute of measurement. The objective of this study was to determine the particle number concentrations between large and small particles, and the large-particle reading was subtracted from the small-particle reading. These values were multiplied by 100 to obtain the number of particles per cubic foot of the air. Finally, the particle number concentrations were converted to $PM_{2.5}$, using a formula proposed in previous studies [5, 17].

In addition to the indoor $PM_{2.5}$ measurements, 26 outside air measurements were conducted to provide comparative data; however, one measurement was incomplete and excluded from the analysis. $PM_{2.5}$ data were analyzed using MS Excel and SPSS version 24. The average $PM_{2.5}$, concentration data for each minute's number of particle concentrations reported by Dylos DC1700 were generated for each HV. The means and medians of the average $PM_{2.5}$ concentration were compared based on venue type, size of the venue, compliance status (compliant vs. non-compliant), active tobacco smoke, and other sources of smoke. Statistical significance was set at $p < 0.05$. Additionally, the indoor $PM_{2.5}$ concentrations (μg/m3) in the current study were compared with the standard air quality index breakpoints over a 24-hour average. The five unhealthy for sensitive air quality include: good (0.0-15.0 μg/m3), moderate (15.1-40.0 μg/m3), unhealthy for sensitive groups (40.1-65.0 μg/m3), unhealthy for all (65.1-250 μg/m3), and hazardous (>250 μg/m3) [25]. For each type of venue, the percentage (%) greater than the average WHO 24-hour level (15 μg/m3), with a 95% confidence interval (CI), was calculated. As checklist for submission of this manuscript, we have used STROBE cross sectional reporting guidelines [26].

3. Results

3.1. General characteristics of the HVs

Data from only 144(93.5%) of the 154 HVs were used for the final analysis, as four venues were measured for less than 30 min, and six were measured incorrectly. Most of the HVs included in this study were selected from Bole Sub-city, Woreda 03 (n=38, 26%), Nifas-Silk-Lafto sub-city, Woreda 01 (n=26,18.1%,) and Kirkos sub-city, Woreda 02 (n=24, 16.7%) (Table1). Approximately 27% (n=39) were bars and restaurants, 17.4% (n=25) were bars, and 15.3% (n=22) were night clubs. Most venues (88.9%, n=128) had only indoor facilities, whereas 11.1% (n=16) had both indoor and outdoor facilities. Considering the potential accommodation size of the venues, 42.4% (n=61) were categorized as large (>45 persons), 34.7% (n=50) as medium (30-45 persons), and the remaining 22.9% (n=33) as small (<30 persons) (Table 1).

Table 1. Characteristics of hospitality venues by sub-city and woreda.

	Name of Sub-city						Total
	Addis Ketema	**Arada**	**Bole**	**Lideta**	**Kirkos**	**Nifas-Silk Lafto**	
	n (%)	**n (%)**	**n (%)**	**n (%)**	**n (%)**	**n (%)**	**n (%)**
Type of venue							
Restaurant	2 (14.3)	1 (5.0)	4 (10.5)	3 (13.6)	3 (12.5)	3 (11.5)	16 (11.1)
Café and Restaurant	2 (14.3)	3 (15.0)	3 (7.9)	4 (18.2)	2 (3.8)	1 (3.8)	15 (10.4)
Bar and restaurant	3 (21.4)	5 (25.0)	12 (31.6)	5 (22.7)	5 (20.8)	9 (34.6)	39 (27.1)
Hotel	2 (14.3)	1 (5.0)	4 (10.5)	1 (4.5)	2 (8.3)	1 (3.8)	11 (7.6)
Grocery	3 (21.4)	1 (5.0)	4 (10.5)	4 (18.2)	2 (8.3)	2 (7.7)	16 (11.1)
Bar	2 (14.3)	4 (20.0)	4 (10.5)	3 (13.6)	5 (20.8)	7 (26.9)	25 (17.4)
Night-club/lounge	0.0	5 (25.0)	7 (18.4)	2 (9.1)	5 (20.8)	3 (11.5)	22 (15.3)
Nature of venue							
Indoor and outdoor facility	2 (14.3)	1 (5.0)	1 (2.6)	1 (4.5)	1 (4.2)	10 (38.5)	16 (11.1)

Only indoor facility	12(85.7)	19(95.0)	37 (97.4)	21 (95.5)	23(95.8)	16 (61.5)	128 (88.9)
Venue size							
Small (<30 persons)	6 (42.9)	3 (15.0)	9 (23.7)	9 (40.9)	3 (12.5)	3 (11.5)	33 (22.9)
Medium (30-45 persons)	6 (42.9)	12(60.0)	4 (10.5)	7 (31.8)	9 (37.5)	12 (46.2)	50 (34.7)
Large (>45 persons)	2 (14.3)	5 (25.0)	25 (65.8)	6 (27.3)	12 (50.0)	11 (42.3)	61 (42.4)
Total, n (%)	14 (9.7)	20(13.9)	38 (26.4)	22 (15.3)	24 (16.7)	26 (18.1)	144(100.0)
Outside $PM_{2.5}$ measurement	3 (12.0)	4 (16.0)	6 (24.0)	5 (20.0)	3 (12.0)	4 (16.0)	25 (100.0)

Active tobacco smoking was observed in various hospitality venues, with the highest prevalence observed in bars (28.6%) followed by nightclubs. No active tobacco use was observed in the restaurants. Additionally, at least one other source of smoke, such as an open kitchen, coal, or candle, was present in 43.7% of the restaurants and 19.7% of cafés and restaurants (Figure 1).

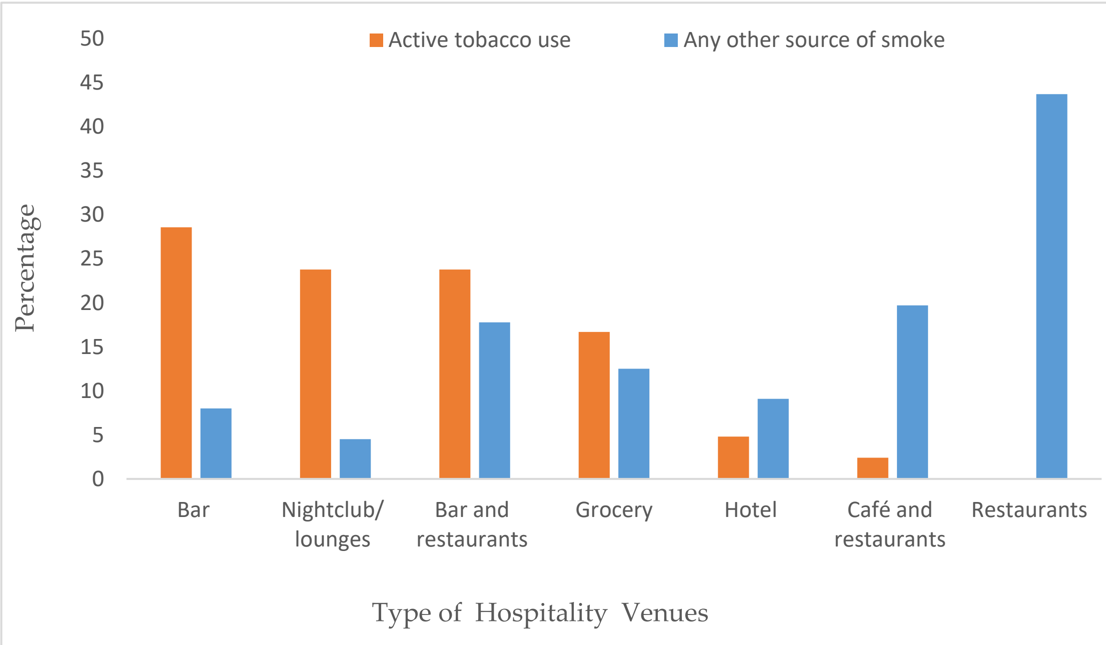

Figure 1. Source of smoke in the hospitality venues in Addis Ababa

3.2. $PM_{2.5}$ concentrations in indoor hospitality venues

The overall mean and median $PM_{2.5}$ concentrations for indoor measurements were 37.23 μg/m^3 and 18.92 μg/m^3 (IQR: 23.26), respectively; and for outside measurements these were 15.89 μg/m^3 and 14.53 μg/m^3 (IQR: 8.44), respectively. The outside $PM_{2.5}$ concentrations (15.92 μg/m^3) in our study were almost equivalent to the WHO's 24-hour average $PM_{2.5}$ level (15 μg/m^3). Table 2 shows the $PM_{2.5,}$ levels across the different types of HVs, nature, and size of the venues. The median concentrations of $PM_{2.5}$were higher in restaurants (21.91 μg/m3, IQR:29.45), bars (21.61 μg/m^3, IQR:28.85), and groceries (21.39 μg/m^3, IQR:11.43). Interestingly, the median $PM_{2.5}$ level in nightclubs/lounges (12.12 μg/m^3, IQR: 48.07) was lower than in the other HV categories, despite their mean $PM_{2.5}$

level (45.28 μg/m³) being higher, except for restaurants which had a mean of 60.4μg/m³. The median $PM_{2.5}$ concentrations were similar across the three sizes of the HVs.

Table 2. Indoor PM2.5 concentrations (μg/m³) by the type and size of hospitality venues.

Type and nature of venue	**n (%)**	**Mean**	**Median**	**IQR***	**Min**	**Max**	***Median P-value****
Restaurant	16 (11.1)	60.40	21.91	29.45	6.99	338.55	
Café and restaurant	15 (10.4)	26.84	17.46	16.50	8.62	121.93	
Bar and restaurant	39 (27.1)	38.57	19.27	36.80	6.19	164.10	
Hotel	11 (7.6)	20.46	15.48	17.77	8.73	56.97	
Grocery	16 (11.1)	26.70	21.39	11.43	10.63	84.60	
Bar	25 (17.4)	33.50	21.61	28.85	4.93	197.84	0.307
Nightclub/lounge	22 (15.3)	45.28	12.12	48.07	4.88	258.84	
Nature of the venue							
Indoor and outdoor facility	16 (11.1)	28.36	23.90	26.39	6.00	63.56	0.426
Only indoor facility	128(88.9)	38.35	17.94	23.76	4.88	338.55	
Venue size							
Small (<30 persons)	33 (22.9)	36.02	19.96	36.76	8.62	258.84	
Medium (30-45 persons)	50 (34.7)	32.42	17.05	18.75	4.88	197.84	0.780
Large (>45 persons)	61 (42.4)	41.79	19.27	25.11	5.06	338.55	
Indoor $PM_{2.5}$ concentrations	144 (100)	37.23	18.92	23.09	4.88	338.55	
Outdoor $PM_{2.5}$ concentrations	25	15.92	14.20	8.97	5.08	41.89	

*IQR= Interquartile range; **The significance level is 0.05.

3.3. Compliance to smoke-free law in hospitality venues

Six out of ten cafés, restaurants, and hotels complied with all smoke-free laws, while groceries, nightclubs/lounges, and bars showed the lowest compliance rates at 0%, 4.5%, and 12%, respectively. Across all HVs, only 23.6% demonstrated full compliance with smoke-free laws (Figure.2).

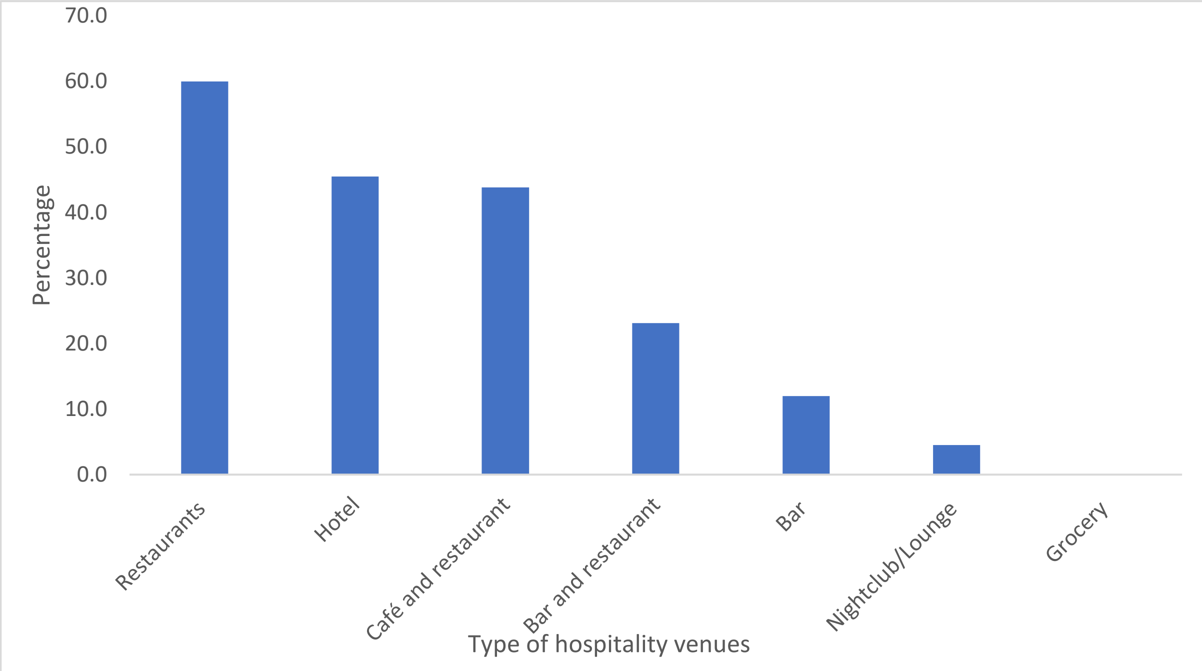

Figure 2. Compliance to smoke free laws indicators by hospitality venues in Addis Ababa

The percentage of HVs with indoor $PM_{2.5}$ concentrations (μg/m^3) exceeding the WHO's 24-hour average (>15 μg/m^3) and their respective 95% CIs. Overall, 63.9% (95% CI: 56-72%) of the HVs had $PM_{2.5}$ concentrations greater than 15 μg/m^3. Groceries (81.3%) had the highest proportion, followed by cafés and restaurants (73.3%), bars and restaurants (69.2%) and restaurants (68.8%). The 95% CIs overlapped, suggesting that there were no significant differences. The proportion of HVs with indoor $PM_{2.5}$ concentrations greater than the WHO's 24-hour average was 75% in venues with both indoor and outdoor facilities, compared to 62.5% in venues with only indoor facilities, with no statistically significant difference observed. In terms of venue size, similar percentages (62.0-66.7%) of the three venue sizes surpassed the WHO's 24-hour average $PM_{2.5}$ (μg/m3) (Table 3).

Table 3. Comparison of indoor PM2.5 concentrations (μg/m^3) of the venues with WHO's 24-hour average.

Type and nature of venue	Number	Percentage (%) greater than the average of the WHO's 24-hour level (15 μg/m^3), (95% CI)
Restaurant	11	68.8 [43 – 94]
Café & Restaurant	11	73.3 [48 – 99]
Bar & Restaurant	27	69.2 [54 – 84]
Hotel	6	54.5 [19 – 90]
Grocery	13	81.3 [60 – 99]
Bar	16	64.0 [44 – 84]
Nightclub/lounge	8	36.4 [15 – 58]
Nature of the venue		
Both indoor & outdoor facility	12	75.0 [51 – 99]
Only indoor facility	80	62.5 [54 – 71]
Venue size		
Small (<30 persons)	22	66.7 [50 – 84]

Medium (30-45 persons)	31	62.0 [48 – 76]
Large (>45 persons)	39	63.9 [52 – 76]
Total (%)	92	63.9 [56 – 72]

Table 4 indicates that 36.1% (n=52) of the HVs had $PM_{2.5}$ concentrations below 15 µg/m3, which was considered good, while 40.3% (n=58) had $PM_{2.5}$ concentrations between 15.1 and 40 µg/m3, categorized as moderate. Approximately 11% (n=16) and 10.4% (n=15) of the venues had $PM_{2.5}$, which is considered unhealthy for sensitive groups and all people, respectively. The air quality in two restaurants and one nightclub/lounge was deemed hazardous. Furthermore, 11.7% (n=15) of the HVs with only indoor facilities, 16% (n=4) of the bars, and two nightclubs/lounges had unhealthy air quality levels.

Table 4. Comparison of indoor $PM_{2.5}$ concentrations (µg/m^3) of the venues with standard air quality index breakpoints, Addis Ababa, December 2022.

Type and nature of venue, n (%)	**Air quality breakpoints (µg/m³, 24-hour average)**				
	Good (0.0-15.0)	**Moderate (15.1-40.0)**	**Unhealthy for sensitive groups (40.1-65.0)**	**Unhealthy for all (65.1-250)**	**Hazardous (>250)**
Restaurant	5 (31.3)	7 (43.8)	2 (12.5)	0.0	2 (12.5)
Café & Restaurant	4 (26.7)	8 (53.3)	2 (13.3)	1 (6.7)	0.0
Bar & Restaurant	12 (30.8)	15 (38.5)	7 (17.9)	5 (12.8)	0.0
Hotel	5 (45.5)	5 (45.5)	1 (9.0)	0.0	0.0
Grocery	3 (18.8)	11 (68.8)	1 (6.3)	1 (6.3)	0.0
Bar	9 (36.0)	10 (40.0)	2 (8.0)	4 (16.0)	0.0
Nightclub/lounge	14 (63.6)	2 (9.1)	1 (4.5)	4 (18.2)	1 (4.5)
Nature of the venue					
Both indoor & outdoor facility	4 (25.0)	8 (50.0)	4 (25.0)	0.0	0.0
Only indoor facility	48 (37.5)	50 (39.1)	12 (9.4)	15 (11.7)	3 (2.3)
Venue size					
Small (<30 persons)	11 (33.3)	12 (36.4)	5 (15.2)	4 (12.1)	1 (3.0)
Medium (30-45 persons)	19 (38.0)	21 (42.0)	5 (10.0)	5 (10.0)	0.0
Large (>45 persons)	22 (36.1)	25 (41.0)	6 (9.8)	6 (9.8)	2 (3.3)
Total, n (%)	52 (36.1)	58 (40.3)	16 (11.1)	15 (10.4)	3 (2.1)

Figure 3 shows a $PM_{2.5}$ concentration (µg/m3) measurement in one of the nightclubs/lounges where several people were using tobacco products. This HV recorded a hazardous level of $PM_{2.5}$ concentration (>250 µg/m3) at the time of indoor data collection.

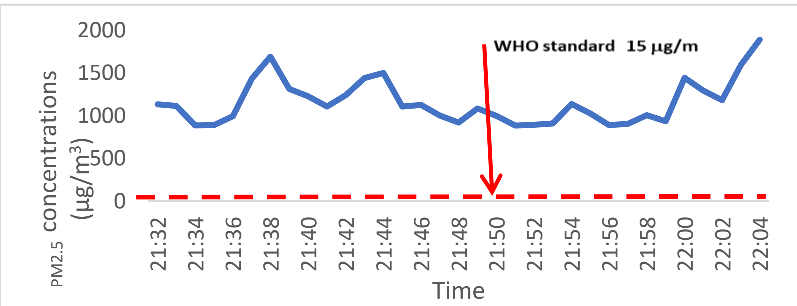

Fig.3 $PM_{2.5}$ (µg/m^3) measurement at nightclub with several tobacco users at Addis Ababa, December,2022

Table 5 shows the $PM_{2.5}$ concentrations (μg/m³) inside the HVs, based on compliance with smoke-free laws. Venues where smoking was observed had a median $PM_{2.5}$ concentration of 22.56 μg/m³ (IQR: 48.41), which was greater than the median concentration of 17.06 μg/m³ (IQR: 17.54) in venues without smoking. Although the difference was not statistically significant (p=0.099), smoking venues had higher median $PM_{2.5}$. The presence of multiple smokers, shisha equipment, and tobacco product sales in indoor spaces were all significantly associated with higher $PM_{2.5}$ concentrations ($p< 0.005$). Although open kitchens and coal smoke contributed to an increase in $PM_{2.5}$, none of these associations were statistically significant.

Table 5. Indoor $PM_{2.5}$ concentrations (μg/m³) by smoke free law indicators and other sources of smoking in Addis Ababa, December 2022.

	N (%)	Mean	Median	IQR*	Min	Max	*Median P-value***
Cigarettes smoking in the indoor space							
Yes	42 (29.2)	46.17	22.56	48.41	4.88	258.84	
No	102 (70.8)	33.53	17.06	17.54	4.93	338.55	0.099
Number of people smoking a cigarette							
None	102 (70.8)	34.31	17.06	19.99	4.88	338.55	
One	19 (13.2)	21.73	14.93	13.23	6.55	66.40	0.001**
Two	8 (5.6)	53.17	21.20	34.44	5.68	258.84	
Three or more	15 (10.4)	68.11	49.94	62.99	8.41	246.06	
Shisha equipment observed							
Yes	5 (3.5)	139.8	96.4	233.8	32.6	348.04	0.02 **
No	139(96.5)	28.5	16.7	17.26	4.7	318.5	
'No smoking sign' posted in the indoor space							
Yes	85 (59.03)	33.9	17.3	17.36	4.95	348.04	
No	59(40.97)	30.2	15.5	21.24	4.7	247.9	
Smoking tobacco within 10 meters from any air intake mechanism							0.884
Yes	83	30.3	15.8	14.28	4.7	348	0.244
No	61	35.26	17.35	19.3	5.66	318.47	
Sale of tobacco products in the indoor space							
Yes	3(2.08)	88.8	58.4	-	20.89	187.13	
No	141(99.92)	31.2	16.8	18.12	4.7	348.04	0.043**
Door/window opened(n=143)							
Yes	127 (88.8)	34.12	18.42	22.20	5.06	338.55	
No	16 (11.2)	62.63	21.81	65.98	4.88	258.84	0.768
Open kitchen							
Yes	6 (4.2)	69.49	48.27	113.18	17.46	164.10	
No	138 (95.8)	35.81	18.17	21.59	4.88	338.55	0.677
Presence of coal smoke							

Yes	8 (5.6)	76.32	32.99	63.9	14.54	338.55	
No	136 (94.4)	34.92	18.06	22.79	4.88	295.35	0.275
Total, n (%)	144	37.22	18.92	23.26	4.88	33.55	

*IQR=Interquartile range; **The significance level is 0.05.

4. Discussion

This study is the first to be conducted in Ethiopia in accordance with smoke-free laws that measures $PM_{2.5}$ concentration in HVs. The mean and median $PM_{2.5}$ concentrations for indoor measurements were 37.23 μg/m^3 and 18.92 μg/m^3, respectively, compared to outdoor measurements of 15.89 μg/m^3 and 14.53 μg/m^3, respectively. Approximately 36% of the HVs had $PM_{2.5}$ concentrations below 15 μg/m^3, while 40.3% had concentrations between 15.1 μg/m^3 and 40 μg/m^3. Approximately 11% and 10.4% of the venues had $PM_{2.5}$ values considered unhealthy for sensitive groups and unhealthy for all people, respectively. Two restaurants and one nightclub had $PM_{2.5}$ levels above 250 μg/m^3, posing a health risk to both employees and customers in these establishments. Evidence for tobacco use in the indoor space of HVs was significantly associated with higher median $PM_{2.5}$ concentrations ($p< 0.005$).

The average outdoor $PM_{2.5}$ concentration was comparable to the WHO's 24-hour average outdoor measurement (15μg/m^3) [25], but it was significantly lower than the indoor measurements, indicating potential $PM_{2.5}$ emissions in indoor HVs. Previous research in different settings has also reported higher indoor $PM_{2.5}$ concentrations than outdoor measurements [20, 27]. In our study, the presence of multiple smokers, shisha equipment, and the sale of tobacco products in indoor spaces were significantly associated with a higher median $PM_{2.5}$. We also found hazardous levels of $PM_{2.5}$ in a nightclub/lounge during new year celebrations, where several people were smoking tobacco products. Our findings align with a study in Ghana [29] which reported higher $PM_{2.5}$ concentrations (28.3 μg/m^3) in HVs with indoor tobacco smoking compared to smoke-free spaces (12.3 μg/m^3). Consistent with other studies, our research demonstrates an increase in $PM_{2.5}$ concentrations in the presence of tobacco smoke [9, 28, 29].

In this study, 63.9% of HVs had indoor $PM_{2.5}$ concentrations (μg/m^3) higher than the WHO's 24-hour average (>15 μg/m3) [25]. These estimates are notably high in countries with comprehensive smoke-free laws. However, no studies conducted in Ethiopia before or after the approval of smoke-free laws, and we lack a reference to compare our findings. A study in Turkey reported that cigarette smoking was observed in 67.5% of HVs, with a median $PM_{2.5}$, which was five times higher than ours, even after the implementation of smoke-free laws [3]. Conversely, studies in Michigan [30] and Scotland [9] reported a significant decline in active indoor smoking and $PM_{2.5}$ concentration following the implementation of the laws. This suggests a potential impact of strong regulatory measures on reducing SHS exposure.

Although no active tobacco smoking was observed in restaurants, 68.8% of them had $PM_{2.5}$ concentrations exceeding 15 μg/m^3. This can be explained by $PM_{2.5}$, emissions resulting from biomass fuel combustion, fuel combustion for heating, vehicular traffic, and other human activities [32, 33]. Studies conducted in rural Malawi, Ethiopia, and Uganda [31, 32, 33] also have reported similar results.

Approximately 24% of HVs complied with all smoke-free law indicators: cigarette smoking (29.2%) and shisha smoking (6.2%) were observed. Notably, bars and nightclubs/lounges had the lowest smoke-free compliance rates and active tobacco use was observed. This finding aligns with previous studies that reported higher tobacco use and poorer compliance with smoke-free laws in bars and pubs than in hotels and other HVs [13, 33]. Ethiopia has strong tobacco control laws, as evidenced by the comprehensive tobacco control law enacted in 2019 and reinforced by the Tobacco Control Directive

(Number 771/2021) in 2021[28]. The Proclamation mandates that indoor public spaces, public transport, and workplaces must be completely free of smoke [11]. However, our study reveals suboptimal implementation of these laws in HVs, particularly in bars and nightclubs/lounges where law enforcement activities are limited.

5. Limitations

The $PM_{2.5}$ concentration was measured over a 30-minutes period while WHO's air quality standard employed data from a 24- hour measurement. This difference in duration might affect comparability of the results. However, the result from this study indicated that average outdoor $PM_{2.5}$ concentration measured was comparable to the WHO's 24-hour average outdoor measurement. This increases our confidence that the higher average indoor PM2.5 concentration measurement was due to a potential source of $PM_{2.5}$ emission in the indoor HVs environment. Though tobacco is the main source of $PM_{2.5}$ emission, biomass fuels, fuel combustion for heating, vehicles, and similar human activities can as well be sources [5,31,32,33].

6. Conclusions

Compliance with smoke-free law indicators for HVs in Addis Ababa was suboptimal. Active tobacco smoking is more common in bars and nightclubs than other types of HVs. $PM_{2.5}$ concentrations in 64% of HVs exceeded the average WHO air quality standard. Active use of cigarettes and shisha contributed to elevated $PM_{2.5}$ emissions in HVs. It is crucial to cautiously interpret the high $PM_{2.5}$ concentrations in smoke-free HVs, surpassing the WHO air quality standard, considering other potential sources of $PM_{2.5}$. Further research and interventions are needed to address additional contributors to $PM_{2.5}$ levels in the HVs in Addis Ababa. It is recommended that the enforcement of smoke-free laws, be strengthened, particularly for bars and nightclubs/lounges. We recommend that this study be conducted in other regions of Ethiopia.

Operational definitions

Active smoking: possession or control of a lit tobacco product, including cigarettes, cigars, and shisha, inside or outside the HVs at the time of data collection.

Hospitality venue: An establishment registered under the regulation of the Government of Ethiopia where food and beverages are sold and consumed, namely hotels, restaurants, bars, bars and restaurants, cafés and restaurants, butcher houses and restaurants, grocery, nightclubs, and lounges.

Bar: An establishment where alcoholic drinks and sometimes food is served to clients.

Café: An establishment where simple meals and drinks (such as tea, coffee, and milk) are served to clients.

Compliance: The degree to which HVs fully implement tobacco control laws under the 2019 Ethiopian Tobacco Control Law (Proclamation No.1112/2019).

Grocery: A small store that primarily retails a general range of alcoholic drinks such as liquor, wine, and beer.

Hotel: An establishment offering lodging, food, beverages, and as may be needed, recreational, conference, and similar facilities to clients.

Lounge: a place where customers enjoy alcoholic beverages while listening to soothing music or watching television. In this study, however, lounges serve as nightclubs since the latter is regarded as illegal.

Nightclub: A place of entertainment open to clients at night, usually serving food and liquor and providing music and space for dance.

Restaurant: an establishment offering food and beverage services to clients.

Tobacco product: A product entirely or partly made of tobacco leaf as a raw material that is manufactured for use in smoking, chewing, sucking, or snuffing.

Data availability: The datasets used and analyzed in the current study will be available from the corresponding author upon reasonable request.

Ethics approval: This research was approved by the Ethiopian Public Health Association

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List of Abbreviation: AAU- Addis Ababa University

DSA - Designated smoking area

EAT- East Africa Time

FCTC- Framework Convention on Tobacco Control

GATS- Global Adult Tobacco Survey

HVs- Hospitality Venues

IQR- Inter Quartile Range.

ODK- Open Data Kit

SD- Standard Deviation

SF- Smoke Free

SHS- Second Hand Smoke

PM- Particulate Matter

WHO-World Health Organization

References

1. Avila-Tang E, Elf JL, Cummings KM, Fong GT, Hovell MF, Klein JD, et al. Assessing secondhand smoke exposure with reported measures. Tob Control. 2013;22(3):156-63.
2. Robertson L, Nyamurungi KN, Gravely S, Rusatira JC, Oginni A, Kabwama SN, et al. Implementation of 100% smoke-free law in Uganda: a qualitative study exploring civil society's perspective. BMC Public Health. 2018;18(1):927.
3. Kaplan B, Carkoglu A, Ergor G, Hayran M, Sureda X, Cohen JE, et al. Evaluation of Secondhand Smoke Using $PM_{2.5}$ and Observations in a Random Stratified Sample in Hospitality Venues from 12 Cities. Int J Environ Res Public Health. 2019;16(8).
4. Thangavel P, Park D, Lee YC. Recent Insights into Particulate Matter ($PM_{2.5}$)-Mediated Toxicity in Humans: An Overview. Int J Environ Res Public Health. 2022;19(12).
5. Dobson RS, S. "How do you know those particles are from cigarettes?": An algorithm to help differentiate second-hand tobacco smoke from background sources of household fine particulate matter. Environ Res. 2018;166:344-7.
6. World Health Organization (WHO). WHO global air quality guidelines. Particulate matter (PM2.5 and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Geneva:2021 Available from: https://www.who.int/publications
7. Barnoya J, Monzon JC, Briz P, Navas-Acien A. Compliance to the smoke-free law in Guatemala 5-years after implementation. BMC Public Health. 2016;16:318.
8. Andrew Apsle SS. Secondhand smoke levels in Scottish bars 5 years on from the introduction of smoke-free legislation. Tob Control. 2012;21(5):511-3.
9. Semple S, Creely KS, Naji A, Miller BG, Ayres JG. Secondhand smoke levels in Scottish pubs: the effect of smoke-free legislation. Tob Control. 2007;16(2):127-32.
10. World Health Organization (WHO). WHO Frame Work Convention OnTobacco Control WHO Document Production Services, Geneva, Switzerland.2005.
11. Federal Democratic Republic of Ethiopia. Food and medicine administration Proclamation No. 1112/2019 [Internet]. 2019. Availablefrom:https://www.tobaccocontrollaws.org/files/live/Ethiopia.
12. Bakhturidze G, Peikrishvili N, Gvinianidze K. Impact of comprehensive smoke-free policy compliance on SHS exposure and health condition of the Georgian population. Tob Prev Cessat. 2021;7:70.
13. Singh A, Dobbie F, Kinnunen T, Okello G, Semple S, Boakye Okyere P, et al. Adherence to smoke-free policies in Ghana: Findings from a cross-sectional survey of hospitality venue owners and staff. Tobacco Prevention & Cessation. 2021;7(January):1-13.
14. Karimi KJ, Ayah R, Olewe T. Adherence to the Tobacco Control Act, 2007: presence of a workplace policy on tobacco use in bars and restaurants in Nairobi, Kenya. BMJ Open. 2016;6(9):e012526.
15. World Health Organization (WHO). WHO Framework Convention on Tobacco Control. Geneva, Switzerland.2005
16. Global Adult Tobacco Survey (GATS). Executive summary 2016. Available fromhttps://wwwafrowhoint/sites/default/files/2017-10.
17. Semple S, Ibrahim AE, Apsley A, Steiner M, Turner S. Using a new, low-cost air quality sensor to quantify second-hand smoke (SHS) levels in homes. Tob Control. 2013;24(2):153-8.
18. Addis Ababa City Admnninistration GoE. Sub- Administeration Emperor Menelik Square Arada Sub city Addis Ababa, Ethiopia2023 [Available from: https://cityaddisababa.gov.et/index.php/en.
19. Berhe A ED, Hassen I, Mamaru T, Soressa Y. City profile: Addis Ababa. 2017. Available from: http://moodle.donau-uni.ac.at/ses/.
20. Gravely S, Nyamurungi KN, Kabwama SN, Okello G, Robertson L, Heng KKC, et al. Knowledge, opinions and compliance related to the 100% smoke-free law in hospitality venues in Kampala, Uganda: cross-sectional results from the KOMPLY Project. BMJ Open. 2018;8(1):e017601.
21. Angela Jackson-Morris SS, Ruaraidh Dobson. Air Quality Monitoring Toolkit: Assessing Second-Hand Smoke in Hospitality Venues 2014. Available from: https://theunion.org/sites/default/files/2020-08/pubtc_ToolkitforAirQualityMonitoring.pdf.
22. Ellen Feighery MC, Karen Friend, Benjamin Apelberg, Lisa Hepp, Erika Avila-Tang and Heather Selin. . Assessing Compliance with Smoke-Free Laws. A "How-to" Guide for Conducting Compliance Studies: Tobacco Free Kids, Johns Hopkins Bloomberg School of Public Health, and the International Union Against Tuberculosis and Lung Disease (The Union) 2014 Available from: www.tobaccofreeunion.org.
23. Chowdhury SR, Sunna TC, Das DC, Chowdhury MR, Mahmud HMM, Hossain A. Compliance with smoke-free legislation in public places: An observational study in a northeast city of Bangladesh. PLoS One. 2023;18(4):e0283650.
24. Navas-Acien A, Carkoglu A, Ergor G, Hayran M, Erguder T, Kaplan B, et al. Compliance with smoke-free legislation within public buildings: a cross-sectional study in Turkey. Bull World Health Organ. 2016;94(2):92-102.

25. World Health Organization (WHO). WHO global air quality guidelines: particulate matter (PM2.5 and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide 2021. Available from: https://apps.who.int/iris/handle/10665/345329.
26. Von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies.
27. Hoe C, Ahsan H, Ning X, Wang X, Li D, Wright K, et al. Enforcement agencies and smoke-free policy compliance: An observational study in Qingdao, China. Tob Induc Dis. 2021;19:26.
28. Ethiopian Food and Drug Administeration (EFDA). Tobacco Control Directive No. 771/2021. Addis Ababa, Ethiopia2021.
29. Singh A, Okello G, Semple S, Dobbie F, Kinnunen TI, Lartey KF, et al. Exposure to secondhand smoke in hospitality settings in Ghana: Evidence of changes since implementation of smoke-free legislation. Tob Induc Dis. 2020;18:44.
30. Shamo F, Wilson T, Kiley J, Repace J. Assessing the effect of Michigan's smoke-free law on air quality inside restaurants and casinos: a before-and-after observational study. BMJ Open. 2015;5(7):e007530
31. Saleh S, Sambakunsi H, Makina D, Chinouya M, Kumwenda M, Chirombo J, et al. Personal exposures to fine particulate matter and carbon monoxide in relation to cooking activities in rural Malawi. Wellcome Open Res. 2022;7:251.
32. Tamire M, Kumie A, Addissie A, Ayalew M, Boman J, Skovbjerg S, et al. High Levels of Fine Particulate Matter ($PM_{(2.5)}$) Concentrations from Burning Solid Fuels in Rural Households of Butajira, Ethiopia. Int J Environ Res Public Health. 2021;18(13).
33. Nakora N, Byamugisha D, Birungi G. Indoor air quality in rural Southwestern Uganda: particulate matter, heavy metals and carbon monoxide in kitchens using charcoal fuel in Mbarara Municipality. SN Applied Sciences. 2020;2(12).