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Examining indoor levels of carbon monoxide and black carbon in Metropolitan Atlanta smoking establishments, hookah establishments, and non-smoking venues

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APPROVAL PAGE

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Author’s Statement Page

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Chandan Morris Robbins

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TABLE OF CONTENTS

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LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Black Carbon	BC
Carbon Dioxide	CO_2
Carbon Monoxide	CO
Centers for Disease Control	CDC
Chronic Obstructive Pulmonary Disease	COPD
Environmental tobacco smoke	ETS
Exhaled Carbon Monoxide	eCO
Hookah and smoking establishments	HS
Hookah establishments	H
Interquartile Range	IQR
Metropolitan Statistical Area	MSA
National ambient air quality standards	NAAQS
Non-smoking establishments	NS
Occupational Safety and Health Administration	OSHA
One-Way Analysis of Variance	ANOVA
Organic Carbon	OC
Particulate Matter	PM
Parts per million	ppm
Permissible exposure limit	PEL
Polycyclic aromatic hydrocarbons	PAHs
Second hand smoke	SHS
Smoking establishments	S
Standard Deviation	SD
Standard Error of the Mean	SEM
Time-Weighted Average	TWA
World Health Organization	WHO

ABSTRACT:

Background:

This research is an environmental exposure study examining indoor levels of carbon monoxide and black carbon in Metropolitan Atlanta smoking establishments, hookah establishments, and non-smoking venues. Recently, there has been an increase in the use of shisha or "hookahs" in the U.S. Hookahs are water pipes that are used to smoke specially manufactured tobacco that comes in different flavors. The legal age for smoking hookah is 18 years; however, children of any age may be permitted into a hookah lounge/restaurant depending upon the particular city's ordinances and many U.S. hookah establishments are classified as "family dining." It is a common misconception, amongst hookah smokers, that the practice of hookah is less harmful than smoking cigarettes. Hookahs, like cigarettes, produce environmental tobacco smoke (ETS). ETS poses a tremendous threat to indoor air quality, contains chemicals and particles that are detrimental to one's health, and is extremely dangerous to those who inhale it. Two components of ETS are carbon monoxide (CO) and black carbon (BC). CO exposure may cause headaches, dizziness, disorientation, nausea, fatigue, angina, impaired vision, reduced brain function, and even death. BC may cause respiratory, cardiovascular, pulmonary, gastrointestinal, renal, and dermatologic problems; the most significant endpoint is cancer. Currently, there are no specifically defined standards or regulations for BC under the Indoor Air Quality Guidelines, and to date, there are no indoor air quality regulations for CO, except those pertaining to occupational safety. However, smoking establishments may be exempt from Indoor Air Quality Guidelines for carbon monoxide levels for various reasons (WHO, 2003).

Objective:

The focus of this study was to compare and contrast the levels of CO and BC exposure in cigarette smoking, hookah and non-smoking venues. The results may provide information to refine future standards or regulations for BC and CO.

Methods:

Preliminary data was collected during an air sampling study utilizing the following air quality instrumentation: the MicroAeth AE51 and the Q-Trak Indoor Air Quality Monitor 7565. Three specific types of service venues made up the sampling unit: venues that permit cigarette smoking only, venues that permit hookah smoking only, and venues that do not permit smoking of any kind. A convenience sample of six locations from the Atlanta Metropolitan Statistical Area based upon accessibility to GSU were selected. For categorical variables, frequency distributions were used. For continuous variables, an appropriate measure of central tendency and corresponding measure of dispersion was used. Continuous variables were examined for normality and a quantile plot was used. The unit for CO is ppm (parts per million) and the unit for BC is ng/mg^3. For each variable, appropriate summary statistics were calculated. The median and interquartile range was reported. The primary comparison was assessing the distribution of each pollutant across the venue types (Hookah, Smoking, Non-smoking). Non-parametric statistical tests were applied. The Kruskal-Wallis one-way layout was applied with post hoc multiple comparisons. Spearman correlation coefficients were used to quantify

association between the variables. The level of significance in this study was set at $\alpha=0.05$. Data was analyzed using Microsoft Excel and SAS.

Results:

The study indicates that inhaling ETS from both hookah and smoking establishments may have potential dangers, because the concentration levels of both BC and CO are significantly higher in hookah and smoking establishments versus non-smoking establishments ($p \leq 0.05$). The study also shows that while BC levels in smoking establishments are significantly higher than in hookah establishments, CO levels are significantly higher in hookah establishments than in smoking establishments ($p \leq 0.05$).

Conclusion:

The results of this study do not support the hypothesis that the mean level of CO and BC concentrations in industry venues that permit cigarette smoking is equal to the mean level of CO and BC concentrations in hookah establishments. Additionally, the mean level of CO and BC concentrations in industry venues that permit cigarette smoking and venues that permit hookah smoking do not equal the mean level of CO and BC concentrations in non-smoking establishments. The results of this study advance scientific knowledge on the factors influencing tobacco smoke pollution and inform public health advocates and decision makers on smoking policy needs. Additional monitoring is necessary to draw more divisive conclusions on BC and CO levels in hookah venues. Currently, local, city, and state laws regulate smoke-free policies, and there is a vast need for standardization across these governing regulations. The Food and Drug Administration (FDA) regulates tobacco policies, while indoor air quality is regulated and governed by each individual state's health department. Therefore, it will be necessary for these agencies to collaborate to monitor and assess compliance.

1. INTRODUCTION

1.1 Background

Environmental Tobacco Smoke

Environmental tobacco smoke (ETS), also known as secondhand smoke (SHS), poses a tremendous threat to indoor air quality and is dangerous to those who inhale it (Brownson *et al*., 1997). ETS contain chemicals and particles that are detrimental to one's health. The Centers for Disease Control (CDC) reports that secondhand smoke causes an estimated 41,000 deaths each year among adults in the United States; 7,333 of these deaths from lung cancer and 33,951 deaths from heart disease (CDC, 2018). Two main pollutants in ETS are carbon monoxide (CO) and black carbon (BC) (You *et al*., 2015).

Carbon monoxide is an odorless, colorless, and toxic gas. In addition to measuring the current CO concentration level, another measurement used is the Time-Weighted Average (TWA). This measures a person's average exposure to CO over time, and is measured in ppm. At lower levels of exposure (approximately 9 ppm) over a long period time, CO causes mild effects that are often mistaken for the flu. These symptoms include headaches, dizziness, disorientation, nausea, and fatigue. At moderate concentrations (approximately 10-24 ppm) over a long period time, exposure may result in angina, impaired vision, and reduced brain function. CO at very high concentrations (above 35 ppm) over a long period time can be fatal (Benignus *et al*., 1984). The deleterious effects are due to the formation of carboxyhemoglobin in the blood, which inhibits oxygen intake (EPA, 2015). Common sources of indoor CO include unvented kerosene and gas space heaters, leaking chimneys and furnaces, back-drafting from furnaces, gas water heaters, wood stoves, and fireplaces, gas stoves, generators and other gasoline powered equipment, automobile exhaust from attached garages, and tobacco smoke (CDC, 2014) (EPA, 2015). Worn or poorly adjusted and maintained combustion devices (e.g., boilers, furnaces) can be significant sources, or if the flue is improperly sized, blocked, disconnected, or is leaking. Potential outdoor sources of CO include auto, truck, or bus exhaust from nearby roads or parking areas (CDC, 2014, EPA, 2015).

BC is a component of particulate matter (PM), and is formed by the incomplete combustion of fossil fuels, biofuels, and biomass (EPA, 2014). BC is emitted directly into the atmosphere in the form of particles typically less than 1.0 microns in aerodynamic diameter ($PM_{1.0}$). BC is very small (<100 nm-200 nm) and hence can be deposited in the alveolar region. It is insoluble in water and hence very difficult to remove from the body once inhaled. BC is a major component of “soot,” a complex light-absorbing mixture that also contains some organic carbon (OC). BC is the collective term for a range of carbonaceous substances encompassing partly charred plant residues to highly graphitized soot (EPA, 2014). BC may carry polycyclic aromatic hydrocarbons (PAHs) adsorbed to its surface into the lungs. The soot particles themselves can also cause numerous respiratory and cardiovascular effects as well as premature death (Yixing *et al*., 2016). Many PAHs are only slightly mutagenic or even non-mutagenic in vitro; however, their metabolites or derivatives can be potent mutagens. Exposure to PAH is associated with cancer (Bice, n.d., ASTDR, 2015).

<u>Regulations and Standards for CO and BC</u>

The Clean Air Act requires the Environmental Protection Agency (EPA) to set national ambient air quality standards (NAAQS) for outdoor carbon monoxide levels. The EPA first set air quality standards for CO in 1971. For protection of both public health and welfare, EPA set an 8-

hour primary standard at 9 ppm and a 1-hour primary standard at 35 ppm. Currently, the standards are still set at these levels, and the guidelines are not to be exceeded more than once per year. In a review of the standards completed in 1985, EPA revoked the secondary standards (for public welfare) due to a lack of evidence of adverse effects on public welfare at or near ambient concentrations. The last review of the CO NAAQS was completed in 1994 and the Agency chose not to revise the standards at that time (EPA, 2015). The current Occupational Safety and Health Administration (OSHA) indoor permissible exposure limit (PEL) for carbon monoxide is 50 parts per million (ppm) parts of air (55 milligrams per cubic meter (mg/m^3) as an 8-hour time-weighted average. CO average levels in homes without gas stoves vary from 0.5 to 5 parts per million (ppm). Levels near properly adjusted gas stoves are often 5 to 15 ppm and levels near poorly adjusted stoves may be 30 ppm or higher (EPA, 2015). To date, there are no indoor air quality regulations, except those pertaining to occupational safety.

The Clean Air Act requires the EPA to set national ambient air quality standards (NAAQS) for outdoor particulate matter 2.5 microns or less. Although there is BC in $PM_{2.5}$, and BC's particle size fits this requirement, this standard does not really apply to BC due to the presence of other aerosols. As of December 2012, the standard for primary $PM_{2.5}$ is 12 ppm and secondary is 15 ppm. This is calculated as an annual mean and averaged over 3 years. Currently, there are no defined standards or regulations for BC levels under the Indoor Air Quality Guidelines. Recently, in the Report to Congress on Black Carbon (EPA-450/R-12-001), the EPA has embarked upon an initiative to regulate black carbon separately from other particulate matter substances under the national ambient air quality standards (NAAQS) (EPA, 2012). This is due to the global and regional climate effects due to BC, the impact of emissions mixtures from different source categories, and its deleterious health effects (EPA, 2012). The World Health Organization (WHO) suggests that it is reasonable to assume that the health effects of $PM_{2.5}$ from both indoor and outdoor sources are broadly the same. Therefore, they further state that the WHO air quality guidelines for PM can also be applied to the indoor environment, specifically in the developing world, where large populations are exposed to high levels of combustion particles derived from indoor stoves and fires (WHO, 2005).

Health effects of cigarette and hookah smoke exposure

Smoking cigarettes, over time, can result in damage to organs, blood vessels, skin, and ultimately may result in blindness, cancer, and even death (Sherman, 1991, Onor *et. al*, 2017). Smoking can cause a disease called Chronic Obstructive Pulmonary Disease (COPD), which is very common in older smokers and is an inflammatory reaction to cigarette smoke. Cigarette smoking is the single largest cause of cancer mortality in the U.S. and is associated with cancers of the lung, larynx, oral cavity, pharynx, and esophagus. Cigarette smoke is a contributing cause in the development of cancers of the bladder, pancreas, uterus, cervix, kidney, stomach, and some leukemia. Smoking is also a major cause of heart disease, bronchitis, emphysema, and stroke and contributes to the severity of colds and pneumonia (EPA, 2014, Onor *et. al*, 2017).

The use of hookahs has been on the rise in the U.S. Approximately 200–300 new hookah cafés opened in the U.S. between 1999 and 2004, usually in college towns (Primack *et al*., 2008). Hookahs are water pipes that are used to smoke specially manufactured tobacco that comes in different flavors, such as apple, mint, cherry, chocolate, coconut, licorice, cappuccino, and watermelon (Scott-Sheldon & Stroud, 2018). Hookahs can also contain herbal, non-tobacco molasses (although this is less common and rarely available in hookah establishments). In most states in the U.S., the legal age for smoking hookah is 18 years; however, children of any age may be permitted into a hookah lounge/restaurant depending upon the particular city's ordinances (Jacob *et al*., 2013). There are numerous health effects associated with smoking hookahs (Wong *et al*., 2016). For example, the charcoal used to heat the tobacco can raise health risks by producing high levels of carbon monoxide, metals, and cancer-causing chemicals. Even after it has passed through water, the smoke from a hookah has high levels of these toxic agents (Cobb *et al*., 2010). Hookah tobacco and smoke contain several toxic agents known to cause lung, bladder, and oral cancers (Hakim *et al*., 2011). Tobacco juices from hookahs irritate the mouth and increase the risk of developing oral cancers. Hookah tobacco and smoke contain many toxic agents that can cause clogged arteries and heart disease. Infections may be passed to other smokers by sharing a hookah (Hakim *et al*., 2011). Babies born to women who smoked water pipes every day while pregnant weigh less at birth (at least 3½ ounces less) than babies born to nonsmokers. Babies born to hookah smokers are also at increased risk for respiratory diseases (Jacob *et al*., 2013).

It is a common misconception amongst hookah smokers that the practice of hookah is less harmful than smoking cigarettes (Aslam *et al*., 2014). However, a study conducted by Maziak *et al*. demonstrated that hookah smoking has many of the same health risks as cigarette smoking (2007). Water pipe smoking delivers nicotine—the same highly addictive drug found in other tobacco products. The tobacco in hookahs is burned (exposed to high heat) and the smoke is at least as toxic as cigarette smoke. Because of the way a hookah is used, smokers may absorb more of the toxic substances also found in cigarette smoke than cigarette smokers do. An hour-long hookah smoking session involves 200 puffs (approximately 20 grams), while smoking an average cigarette involves 20 puffs (approximately 0.7 grams). The amount of smoke inhaled during a typical hookah session is about 90,000 milliliters (mL), compared with 500–600 mL inhaled when smoking a cigarette (Maziak *et al*., 2007). Although it is common for hookahs to be shared in a social setting, the exposure for one person would still exceed that of a cigarette smoker, as 50 puffs and 22,500 mL (approximately 5 grams) would be consumed by one person during a session sharing the hookah with 3 additional people.

1.2 Purpose of Study

Due to the growth in the number of hookah venues and their common classification as "family dining," children may be exposed to high pollution levels. The focus of this study is to examine indoor levels of CO and BC in Metropolitan Atlanta smoking establishments, hookah establishments, and non-smoking venues in order to address the rationale for more specifically defined standards or regulations for BC and CO under the Indoor Air Quality Guidelines. Although there have been approximately nine studies performed to examine indoor levels of total $PM_{2.5}$ in hookah establishments, there is a vast gap in the research area examining indoor levels of BC and CO specifically. To date, only two studies have been performed, and there have been no studies conducted in Atlanta, Georgia. This study will attempt to narrow that research gap by examining indoor levels of CO and BC in Metropolitan Atlanta smoking establishments, hookah establishments, and non-smoking venues.

1.3 Research Questions

The following research questions will guide this study:

1) Does the CO concentration differ between hookah establishments compared to service industry venues that permit cigarette smoking, and non-smoking venues?

2) Does BC concentration differ between hookah establishments compared to service industry venues that permit cigarette smoking, and non-smoking venues?

2. REVIEW OF THE LITERATURE

2.1 ETS Exposure in Cigarette Smoking Verses Hookah Smoking Establishments

There have been numerous studies performed in order to demonstrate the effect of ETS on respiratory symptoms and exhaled carbon monoxide (ECO) levels in subjects exposed to both cigarette and waterpipe ETS as compared to those recorded in non-smokers. ECO is a candidate breath biomarker of pathophysiological states, including smoking status and inflammatory diseases of the lung and other organs (Ryter & Choi, 2013). In one study by Kumar *et al.*, three groups of individuals: nonsmokers exposed to ETS from waterpipe, non-smokers exposed to ETS from cigarettes, and nonsmokers who were not exposed to any type of smoke were examined. Results of the study show, that the expired air CO level was significantly higher ($p = 0.018$) in the breath of passive smokers exposed to waterpipe smoke, followed by those exposed to cigarette smoke and was lowest in the non-exposed group. These results were confirmed by multivariate analysis and dose-effect relationship between duration of exposure and elevated level of carbon monoxide (Kumar *et al.*, 2011). In another study, Czogala utilized a complex analytical method, which was a complex measurement process to perform quantitative analysis of exposure of passive smokers to CO from tobacco smoke. This allowed for the quantification of exposure of passive smokers to CO in various indoor environments. Results indicate that passive smokers are exposed to levels ranging from 10-20 ppm in nightclubs and taverns, and levels ranging from 5-10 ppm in smoking restaurants (Czogala &

Goniewicz, 2005). Carbon monoxide levels are typically less than 1 ppm in establishments where smoking is not allowed (Benignus *et al*., 1984).

Several studies have also been performed in order to assess the exhaled CO levels of hookah lounge patrons. In one study, Barnett *et al.*, using traditional bar patrons as a comparison, patrons exiting hookah establishments and traditional bar establishments in a campus community were tested for their levels of CO. Results from analysis conducted indicate that patrons of hookah establishments had significantly higher CO levels (mean 30.8 ppm, SD: 27.41 ppm) compared to patrons of traditional bars (mean 8.9 ppm, SD: 10.73 ppm). Moreover, respondents who indicate no cigarette use in the past month but had visited a hookah lounge still demonstrated significantly higher mean CO values (28.5 ppm, SD: 26.76 ppm) compared to patrons exiting traditional bars (8.0 ppm, SD: 9.05 ppm). Current cigarette smokers also produced significantly more CO if exiting a hookah lounge (34.7 ppm, SD: 27.71 ppm) compared to a traditional bar (13.3 ppm, SD: 15.26 ppm). These results indicate that CO levels may be higher for patrons of hookah lounges, for both current and non-cigarette smokers. Interestingly, users reported that they perceived hookah to be less harmful than cigarettes. Hence, the greater CO exposure for hookah users observed in this study is not consistent with that perception (or misconception) (Barnett *et al.,* 2011).

There have been a number of studies performed that examine the toxicants produced by ETS from cigarettes. However, there have been a limited number of studies performed on the exposure to PM (specifically black carbon) from cigarette smoke. Amongst the few studies available, Al-sarraf *et al.* found that PM from cigarettes has emission factor 8–20 mg per cigarette, and 0.07 mg per minute of $PM_{2.5}$. Another study observed the significant increase in indoor exposure level of $PM_{2.5}$, when the number of smokers increased inside an indoor area and demonstrated the unacceptably high levels of indoor air pollution $PM_{2.5}$ exposure associated with second hand smoke at various entertainment venues (Al-sarraf *et al.,* 2015). Additionally, evidence from the International Indoor Air Monitoring Study based on measurements conducted in 40 cafes or restaurants in Aleppo, Syria, suggests that the sites far exceed EPA as well as European limits (Maziak *et al.*, 2007). The average $PM_{2.5}$ levels in these venues were 464 mg/m^3, one of the highest values when compared to other studies. As a result of these findings, there have been a limited amount of studies performed on black carbon exposure during hookah smoking in attempts to duplicate the results. In one study by Maziak *et al.*, PM emissions ($PM_{2.5}$, PM_{10}) were examined after laboratory sessions in which 20 individuals used a waterpipe to smoke tobacco and 20 individuals smoked a cigarette (10 for each particle-size/smoking-method), as well as 10 waterpipe and 10 cigarette smoldering sessions (i.e., without a smoker). The study found that hazardous PM emission can build up gradually during waterpipe use to reach high levels, whereas comparable levels are reached faster during cigarette smoking. The clear implication of these findings is that clean air policies should include waterpipe tobacco smoking, as it can be responsible for the buildup of toxic levels of indoor air pollutants at a slow rate. The author's recommendation is that the public health community should be aware of the hazardous nature of this tobacco use method, both to waterpipe users and to nonusers who are exposed to waterpipe tobacco smoke (Maziak *et al.*,2007). A potential limitation to these types of studies is that the black carbon concentration was not directly examined; therefore, only assumptions for the total black carbon concentration out of the total particle number at $PM_{2.5}$ can be made.

While there have been several studies performed which examine the exposure to total $PM_{2.5}$ and CO in hookah smoke, this research only found two studies which examine the exposure to BC, specifically, from hookah smoke. Amongst the few studies available, Zhou *et al*. examined air quality in New York City (NYC) hookah bars. In this study, air samples were collected in eight hookah bars in NYC during the summer and fall of 2013. Real-time measurements of fine particulate matter ($PM_{2.5}$), black carbon (BC), carbon monoxide (CO), integrated samples of total gravimetric PM, elemental carbon (EC), organic carbon (OC), and nicotine were collected in 1–2 hour sessions. Results of this study demonstrated that levels of indoor air pollution increased with increasing numbers of active hookahs smoked. The mean real time $PM_{2.5}$ level was 1179.9 $\mu g/m^3$ (SD: 939.4 $\mu g/m^3$), whereas the filter-based total PM mean was 691.3 $\mu g/m^3$ (SD: 592.6 $\mu g/m^3$). The mean real time BC level was 4.1 $\mu g/m^3$ (SD: 2.3 $\mu g/m^3$), OC was 237.9 $\mu g/m^3$ (SD: 112.3 $\mu g/m^3$), and CO was 32 ppm (SD: 16 ppm). Airborne nicotine was present in all studied hookah bars (4.2 $\mu g/m^3$ (SD: 1.5 $\mu g/m^3$) (2015). The study demonstrates that some NYC hookah bars have elevated concentrations of indoor air pollutants and toxicants that may present significant health threat to visitors and employees. Therefore, there is an urgent need for better air quality monitoring in such establishments and policies to combat this emerging public health threat (Zhou *et al*., 2015). Another study by Zhou *et al*. examines secondhand hookah smoke: as an occupational hazard for hookah bar employees. Air samples were collected during the work shift of 10 workers in hookah bars in NYC. Air measurements of fine particulate matter ($PM_{2.5}$), black carbon (BC), carbon monoxide (CO), and nicotine were collected during each work shift. Blood pressure and heart rate, markers of active smoking and secondhand smoke exposure were assessed in workers immediately prior to and immediately after their work shift. Results of the study show the $PM_{2.5}$ and BC concentrations in indoor air varied greatly among the work shifts with mean levels of 363.8 $\mu g/m^3$ and 2.2 $\mu g/m^3$, respectively. The mean CO level was 12.9 ppm with a peak value of 22.5 ppm CO observed in one hookah bar. Heart rate was elevated by 6 beats per minute after occupational exposure; however, this change was not statistically significant. The results of the study indicate that elevated concentrations of CO in hookah bars may result in adverse health effects in employees, suggesting the need for further research and a clear need for better air quality monitoring and policies in such establishments to improve the indoor air quality for workers as well as patrons (Zhou *et al*., 2016).

2.2 Smoke-free Regulations and Indoor Air Quality

There are no specific state or federal policies regulating hookah/waterpipe establishments in the US. There are extensive smoke-free policies and regulations in public venues on manufactured and hand-rolled tobacco products such as cigarettes, cigars, and cigarillos (little cigars). However, smoking establishments do not have to adhere to the Indoor Air Quality Guidelines for carbon monoxide levels, as long as they do not permit patrons under the age of 18, supporting the need for more stringent and uniform smoke-free regulations in public venues (WHO, 2003). Currently, local, city, and state laws regulate smoke-free policies, and there is a vast need for standardization across these governing regulations. There have been numerous studies on the impact of smoke-free regulations on indoor air quality in public venues. Previous studies demonstrate that smoke-free regulations have a positive impact on indoor air quality in public venues (Kiyoung *et al*., 2009). These regulations may serve as a model for the policy initiative for hookah/water pipe establishments/restaurants.

Recent studies have shown that smoke-free regulations impact indoor air quality in numerous types of public venues. In one study, Kim *et al.* examined indoor fine particle concentrations ($PM_{2.5}$) in bars before and after implementation of the smoke-free policies based on venue size. Indoor $PM_{2.5}$ concentrations were measured in bars at four time points in Seoul and at two time points in Changwon. The bars were selected using convenience sampling based on the accessibility of the bars, and non-proportional quota samples based on their size. Overall, 336 total samples of indoor $PM_{2.5}$ concentrations in 148 bars were collected. Researchers found that, over the three-year study, implementing smoke-free regulations resulted in a gradual improvement of indoor air quality in all bars. Before any regulations were implemented, indoor $PM_{2.5}$ concentrations in all bars were 2.8 times higher than the NAAQS for daily $PM_{2.5}$. Additionally, the overall indoor $PM_{2.5}$ concentrations in all bars decreased by 73%. The results show gradual improvement in indoor air quality with increasingly stringent smoke-free regulations. These results indicate that banning smoking in all bars effectively improved indoor air quality. It also demonstrated the necessity of how full compliance with strict regulations is needed to further improve indoor air quality in these venues (Kim *et al.,* 2016). Another study Lee *et al*. examined the impact of different strengths of smoke-free air laws put in place to protect the public from the harmful effects of secondhand smoke exposure. In this study, researchers monitored hospitality venues, such as restaurants and bars, in nine Kentucky communities. The investigators measured indoor air quality in seven communities before and after comprehensive smoke-free air laws and in two counties after partial smoke-free air laws. Venues in one community were measured three times; prelaw, after the initial partial law, and after the law was strengthened to cover all workplaces and public places (with few exemptions). A total of 62 venues were measured in seven communities with comprehensive smoke-free air laws. Twenty-one venues were measured in two counties after partial smoke-free air laws were implemented. Indoor $PM_{2.5}$ levels of public venues were measured 156 times in 83 venues in nine communities. Investigators found that the average $PM_{2.5}$ level in 62 hospitality venues in communities before they had smoke-free air laws was 161 µg/m^3. That level is 4.6 times higher than the NAAQS for outdoor air, set by the EPA (35 µg/m^3). Indoor air quality improved by 88% after comprehensive smoke-free air laws were implemented. This study indicates that indoor air quality can be improved by implementation of comprehensive smoke-free air laws (Lee *et al*., 2009).

In another study by Lee *et al.*, the impact of two different smoke-free laws on indoor air quality was assessed. They conducted a quasi-experimental study with two cohorts, comparing the indoor air quality of 20 hospitality venues in Lexington and Louisville, Kentucky. Purposive sampling was used in order to select the venues, and venues were matched according to size and type. Monitoring was conducted by collecting real-time measurements of $PM_{2.5}$ before and after the smoke-free laws went into effect. This study was unique in that it compared two cities with very different smoke-free regulations. For example, in Lexington, the smoke-free ban ensured that enclosed public places are smoke free; moreover, it prohibits smoking in most public places, including, but not limited to, restaurants, bars, bowling alleys, bingo halls, convenience stores, laundromats, and other businesses open to the public. In contrast, Louisville Metro Council passed a partial smoke-free law that allows smoking if establishments derive 25% or more of their sales from alcohol or have a bar area that can be physically separated from a dining area by walls, a separate ventilation system, or both. Results showed that the average indoor PM concentrations in the 9 Lexington venues decreased 91%, from 199 to18 μg/ml^3. The average indoor PM concentrations in the 10 Louisville venues, however, increased slightly, from 304 to 338 μg/ml^3. Investigators also found that PM levels in the establishments decreased as numbers of burning cigarettes decreased. This study is relevant in that it demonstrates that comprehensive and properly enforced smoke-free laws can be an effective means of reducing indoor air pollution. On the other hand, partial smoke-free laws with exemptions, as in Louisville, did not reduce indoor air pollution in the selected venues. This strengthens the argument that local and state policymakers should advocate for the enactment of comprehensive smoke-free laws and avoid partial laws that have no impact on population exposure to secondhand smoke (Lee *et al.*, 2008).

In a global study of Irish pubs by Connolly *et al*, researchers examined and compared indoor air quality in smoke-free versus smoking-permitted venues. Indoor air quality was assessed in 128 Irish pubs in 15 different countries. Air quality was evaluated using an aerosol monitor, which measures the level of $PM_{2.5}$ pollution in the air. A convenience sample was utilized in order to select the venues, and results indicated the overall level of air pollution inside smoke-free Irish pubs was 93% lower than the level found in smoking-permitted pubs. This study provides evidence that the most effective method for reducing ETS exposure in public places is the establishment and implementation of policies requiring smoke-free environments. Hence, reducing the level of indoor air pollution should translate into improved health for both workers and patrons. If more cities and countries adopt these laws, when implemented properly, health benefits worldwide should be seen (Connolly *et al*, 2009).

A cross-sectional study by Buettner-Schmidt *et al*, a stratified random sample of 135 bars and restaurants in North Dakota was conducted in order to describe factors that influenced tobacco smoke pollution levels in various venues. Researchers were also interested in comparing the quantity of tobacco smoke pollution by rurality and by the presence of local ordinances. Lastly, researchers were interested in assessing compliance with state and local laws. This study reported being the first statewide study on tobacco smoke pollution levels in hospitality venues using a random sampling procedure. In this study, indoor air quality indicator of $PM_{2.5}$ was calculated. The average smoking density and occupant density was also calculated, and compliance with state and local smoking ordinances was determined by using observational methods. The results of the study showed that as rurality increased, tobacco smoke pollution in bars increased. It also found that compliance was significantly lower in venues that did not have local governing ordinances. This study is relevant as it adds to understanding of tobacco smoke pollution exposure in rural and non-rural venues. The findings suggest that, the more rural the venue, the higher the tobacco smoke pollution in bars. This is important and supports the theory that people living in rural communities constitute a high-risk population affected disproportionately by tobacco use. The results of this study advance scientific knowledge on the factors influencing tobacco smoke pollution and inform public health advocates and decision makers on smoking policy needs, especially for rural areas (Buettner-Schmidt *et al*, 2015).

3. METHODS AND PROCEDURES

3.1 Context of Study

To determine if the CO and BC concentrations differ between hookah establishments, venues that permit cigarette smoking, and non-smoking venues.

Monitoring Locations

Six Metropolitan Atlanta venues were selected for this study to provide for variation: two cigarette smoking establishments (S); two hookah establishments (H); and two non-smoking establishments (NS). Data reported in this study excludes one of the two cigarette smoking establishments because both cigarette smoking and hookah smoking were observed simultaneously during the sampling time. The availability of instrumentation precluded simultaneous monitoring, therefore, monitoring took place at different days and time. This is appropriate based on the sampling protocol and the information gathered to compare venues across time. Metropolitan Atlanta is the most populous metro area in the state of Georgia and the ninth-largest Metropolitan Statistical Area (MSA) in the United States. In this area, there are numerous venues to choose from, as well as the increasing popularity of hookah smoking establishments. The venues included in this study are located in Fulton, DeKalb, and Fayette Counties (Figure 1).

http://ui.uncc.edu/display/metro-changes-affect-charlotte-and-regions-across-country

Figure 1. Monitoring locations indicated as black dots. Location IDs: A, B, C, D, E, and F.

3.2 Study Design

This study design is an observational air monitoring study. Measurement of continuous BC was made with a MicroAeth AE51 (AethLabs, San Francisco, California). The MicroAeth AE51 provides real-time analysis by measuring the rate of change in absorption of transmitted light due to continuous collection of aerosol deposit on filter (AethLabs, 2018). Measurement of CO was made with a Q-Trak Indoor Air Quality Monitor 7565 (Shoreview, Minnesota). The Q-Trak allows real-time display of CO concentration, with a range from 0 ppm to 500 ppm and an accuracy of ±3% of the reading or 3 ppm, whichever is greater (TSI Incorporated, 2018). Instrumentation was verified for proper functioning and prepared for recording. One of each instrument was used at each location, the filter in the MicroAeth AE51 was changed at the start of each monitoring date, and the flow rate was 98 ml/min in 2014 and 149 ml/min in 2016. The Q-Trak was programmed to record CO, CO_2, temperature, and humidity. After testing at each site, data were downloaded from the instrumentation onto the computer software programs (TrakPro Data Analysis Software and microAeth COM software) that were previously installed. No direct human subject measurements were collected. A convenience sample based upon accessibility to GSU were selected.

3.3 Data Collection

Prior to entering each location, monitoring instruments were powered-on, programmed, and placed in a handbag with a sampling inlet at the bag opening. A central location was selected for seat placement within each monitoring location. The instruments were periodically checked to ensure proper functioning during the collection time frame. Data logs were kept at 15- minute intervals during the sampling time. This data log included the location ID, date, time, total number of people, number of hookahs, and/or the number of cigarette smokers, and relevant comments.

3.4 Statistical Analysis

For categorical variables, frequency distributions were used. For continuous variables, an appropriate measure of central tendency and corresponding measure of dispersion was used. Continuous variables were examined for normality and a quantile plot was used. The unit for CO is ppm and the unit for BC is ng/m^3. For each variable, appropriate summary statistics were calculated. If continuous variables were normally distributed, the mean and standard deviation was reported; if non-normal, the median and interquartile range was reported. The primary comparison was assessing the distribution of each pollutant across the venue types (H, S, NS). Depending on normality of the outcomes, either parametric or non-parametric statistical tests were applied. For a parametric approach, a one-way analysis of variance (ANOVA) with post hoc multiple comparisons was used. If the data were non-parametric, then the Kruskal-Wallis one-way layout was applied with post hoc multiple comparisons. Either Pearson's r or Spearman correlation coefficients were used to quantify association between the variables. The level of significance in this study was set at $\alpha=0.05$. Data was analyzed using Microsoft Excel and SAS.

4. RESULTS

For this study, six different venues were sampled. In 2014, all venues were sampled for 2 hours. For black carbon, cigarette smoking and hookah venues were sampled every 60 seconds, and non-smoking venue was sampled every 300 seconds. For carbon monoxide, cigarette smoking, hookah, and non-smoking venues were sampled every 300 seconds. In 2016, all venues were sampled for 1 hour. For black carbon, cigarette smoking, hookah, and non-smoking venues were sampled every 10 seconds. For carbon monoxide, cigarette smoking, hookah, and non-smoking venues were sampled every 60 seconds. To standardize the data, all measurements were collapsed into 5-minute intervals. Data reported in this study excludes Location D because both cigarette smoking and hookah smoking were observed simultaneously during the sampling time (Table 1).

Location ID	Venue Type	Date	Time	Intervals (Black Carbon)	Intervals (Carbon Monoxide)
A	Hookah	4/22/2014	5:45pm-7:45pm	60 seconds	300 seconds

B	Hookah	4/17/2016	10:50pm-11:50pm	10 seconds	60 seconds
C	Smoking	4/25/2014	2:20pm-4:20pm	60 seconds	300 seconds
D	Smoking	4/18/2016	12:15am-1:15am	10 seconds	60 seconds
E	Non-smoking	4/22/2014	4:20pm-6:20pm	300 seconds	300 seconds
F	Non-smoking	4/17/2016	6:20pm-7:20pm	10 seconds	60 seconds

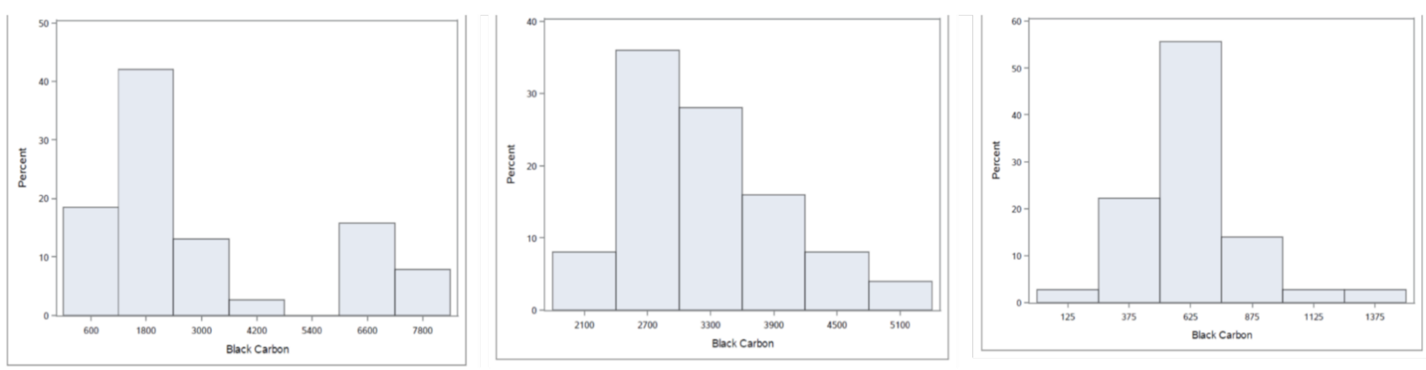
Table 1. Monitoring Location Summary.

Initially, it is necessary to perform a battery of standard calculations on the data. For each variable, the number of samples collected at the monitoring locations (n), median, and IQR (Interquartile Range) were obtained (Table 2).

		Black Carbon (ng/m^3)		Carbon Monoxide (ppm)	
Venue Type	n	Median	IQR (Interquartile Range)	Median	IQR (Interquartile Range)
Hookah	38	1700	2447	5.45	1.4
Smoking	25	3120	1005	0.80	0.1
Non-smoking	38	590	244	0.00	0.00

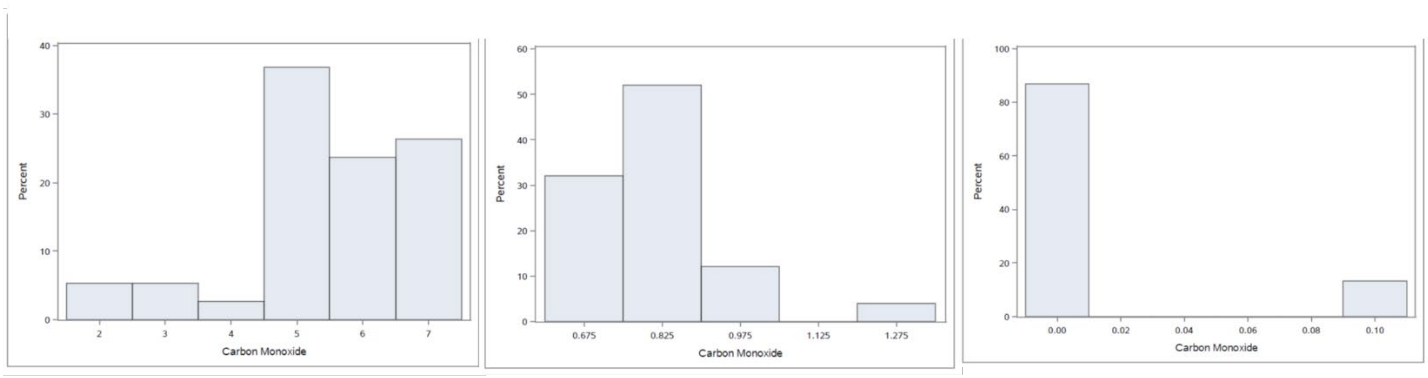
Table 2. Standard Calculations for Black Carbon and Carbon Monoxide for each Monitoring Location.

Histograms for the distribution of black carbon and carbon monoxide for all three types of venues was highly skewed (Figures 2 and 3). For the distribution of black carbon, the histograms for all three venue types displayed a right skewed distribution, where the mean is typically greater than the median and most of the black carbon values fell within the lower range (125 ng/m^3 to 3000 ng/m^3) (Figure 2a., b., and c.). The observed median and standard error of the mean (SEM) for smoking venues was 3120 ng/m^3 (SEM: 145.00 ng/m^3), for hookah venues was 1700 ng/m^3 (SEM: 388.44 ng/m^3), and for non-smoking venues was 590 ng/m^3 (SEM: 39.62 ng/m^3). For the distribution of carbon monoxide, more variation was observed in the histograms of each venue type (Figure 3a., b., and c.). For hookah venues, the histogram displayed a left skewed distribution, and most values fell within higher the range (5 ppm to 7 ppm) (Figure 3a.). For smoking venues, the histogram displayed a right skewed distribution, and most values fell within the lower range (0.675 ppm to 0.975 ppm) (Figure 3b.). For non-smoking venues, the histogram showed a median of 0.0 ppm with a few outliers at 0.10 ppm (Figure 3c.). The observed median and SEM for hookah venues was 5.45 ppm (SEM: 0.21 ppm), for smoking venues was 0.8 ppm (SEM: 0.03 ppm), and for non-smoking venues was less than the instrument's detection limit (SEM: 0.006 ppm) (Figure 3c.). After observing the histograms for the distribution of black carbon and carbon monoxide, nonparametric statistical analysis was performed.



a. Hookah b. Smoking c. Non-smoking

Figure 2. Distribution of Black Carbon for all Three Venue Types (Hookah, Smoking, and Non-Smoking).



a. Hookah b. Smoking c. Non-smoking

Figure 3. Distribution of Carbon Monoxide for all Three Venue Types (Hookah, Smoking, and Non-Smoking).

There are several statistical tests which can be carried out upon non-parametric data, in order to compare two or more groups, to conclude whether or not they are significantly different. After the standard calculations were performed on the data, it was necessary to create box plots of the distribution of black carbon and carbon monoxide, comparing the three different venue types (Figures 4 and 5). For black carbon, the observed median and mean for hookah venues was 1700 ng/m^3 and 2980 ng/m^3, for smoking venues was 3120 ng/m^3 and 3230 ng/m^3, and for non-smoking venues was 590 ng/m^3 and 610 ng/m^3 (Figure 4). For carbon monoxide, the observed median and mean for hookah venues was 5.45 ppm and 5.46 ppm, for smoking venues was 0.80 ppm and 0.80 ppm, and for non-smoking venues was 0.00 ppm and 0.013 ppm (Figure 5).

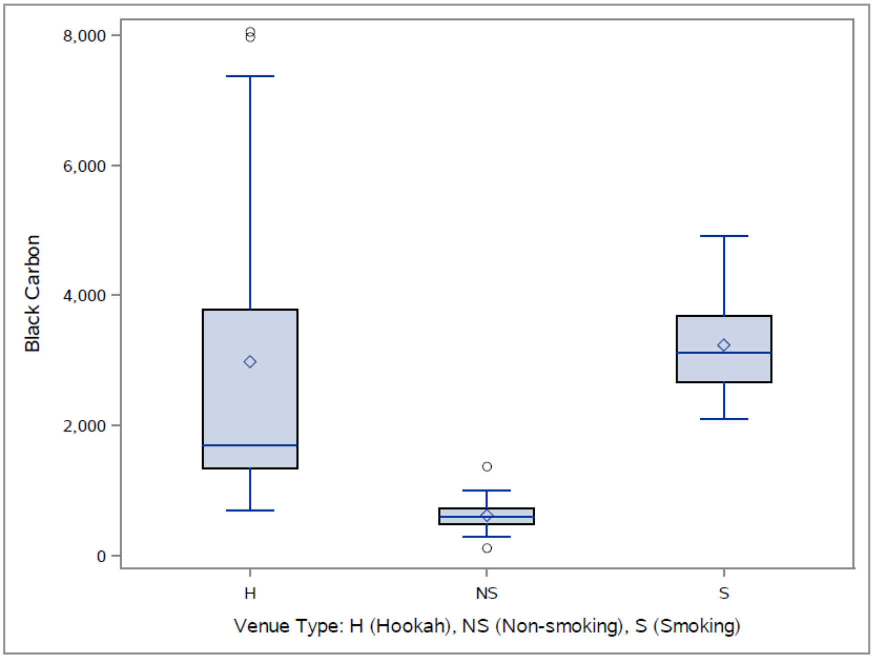


Figure 4. Box Plots of the Distribution of Black Carbon, Comparing the Three Different Venue Types.

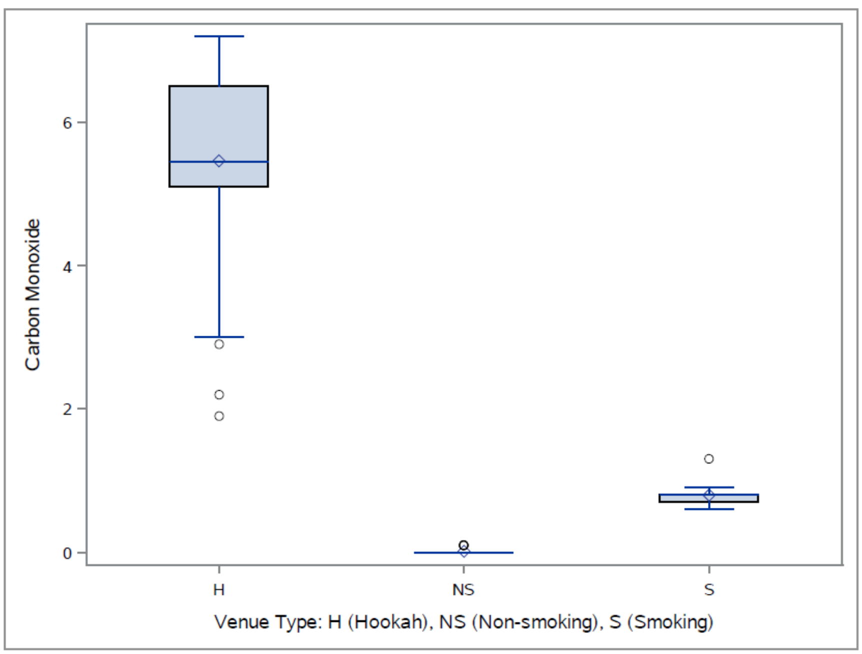


Figure 5. Box Plots of the Distribution of Carbon Monoxide, Comparing the Three Different Venue Types.

To determine whether samples originated from the same distribution when comparing two or more independent samples of equal or different sample sizes, the Kruskal-Wallis one-way layout was applied. Results indicated that there was a significant difference between at least two of the venue types for both black carbon and carbon monoxide. The Kruskal-Wallis Test for black carbon was ($p<0.0001$) and for carbon monoxide was ($p<0.0001$). In order to determine which venue types were significantly different, a pairwise two-sided multiple comparison analysis was performed on each variable. The analysis for both black carbon and carbon monoxide indicate that there is a significant difference between hookah vs. non-smoking establishments, hookah vs. smoking establishments, and smoking vs. non-smoking establishments. For black carbon, hookah vs. non-smoking establishments was $p<.0001$, for hookah vs. smoking establishments was $p=0.02$, and for non-smoking vs. smoking establishments was $p<.0001$. For carbon monoxide, hookah vs. non-smoking establishments was $p<.0001$, for hookah vs. smoking establishments was $p<.0001$, and for non-smoking vs. smoking establishments was $p<.0001$. Time series graphs were also generated for the monitoring locations. Concentration measurements of black carbon and carbon monoxide was graphed as a function of time in five-minute intervals (Figures 6 and 7).

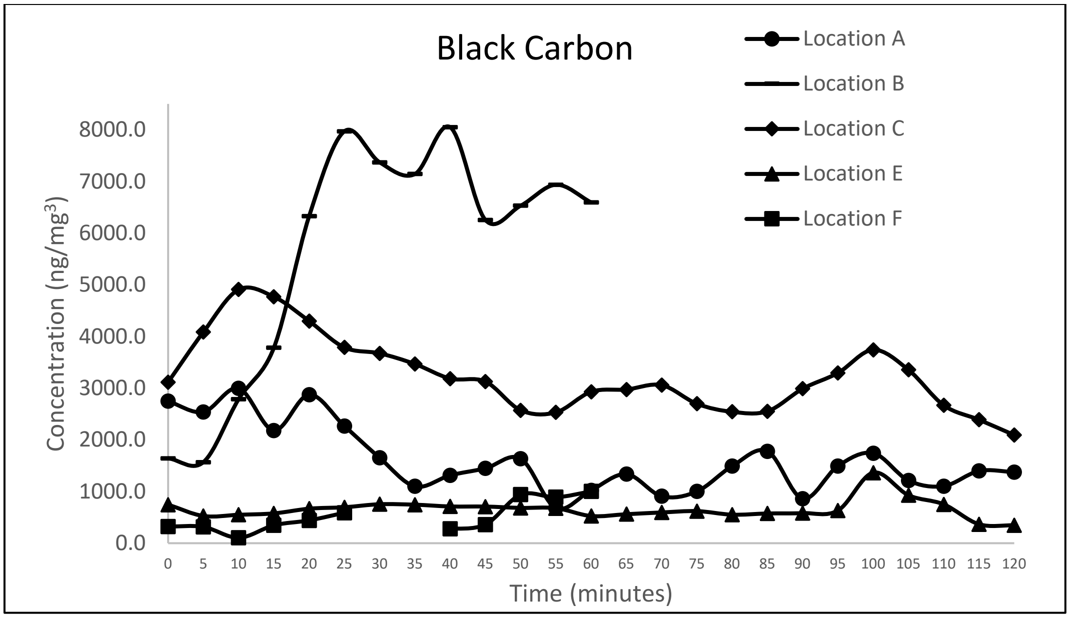


Figure 6. Black Carbon Measurements in all Five Monitoring Locations as a Function of Time in Five-minute Intervals.

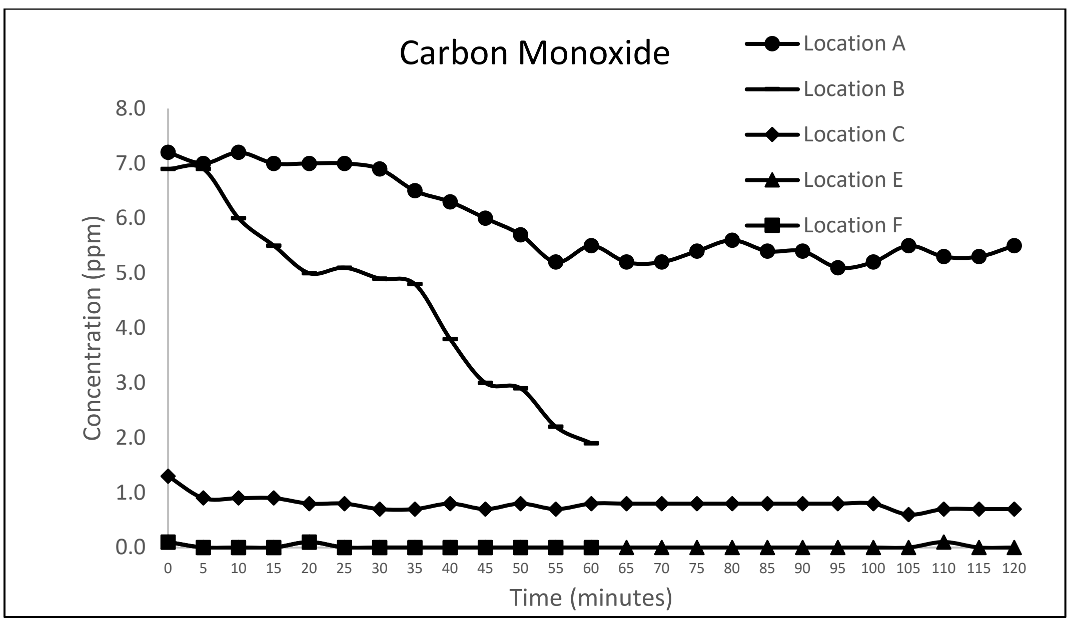


Figure 7. Carbon Monoxide Measurements in all Five Monitoring Locations as a Function of Time in Five-minute Intervals.

The results of the non-parametric tests indicate that both hookah (Locations A and B) and the smoking establishment (Location C) have higher black carbon and carbon monoxide concentrations than the non-smoking establishments (Locations E and F). For black carbon, the smoking establishment (Location C) has a significantly higher concentration than hookah establishments (Locations A and B). For smoking venues, the median is 3120 ng/m^3 (SEM: 145.00 ng/m^3), and for hookah venues, the median is 1700 ng/m^3 (SEM: 388.44 ng/m^3). However, for carbon monoxide, hookah establishments (Locations A and B) have significantly higher concentrations than the smoking establishment (Location C). For hookah venues, the median is 5.45 ppm (SEM: 0.21 ppm), and for smoking venues, the median is 0.8 ppm (SEM: 0.03 ppm).

Next, a Spearman Correlation Coefficients test was performed to determine if any correlations exist between the variables. Spearman's correlation coefficient is a statistical measure of the strength of a monotonic relationship between paired data and is demonstrated as a range between -1 and 1. As a general guide, this study will assume any values .00-.39 have a weak correlation, any values .40-.59 have a moderate correlation, and any values .60-1.0 have a strong correlation. Results of the Spearman's correlation coefficient test shows that there is a moderate correlation between number of smokers and black carbon (0.52); however, there is a strong correlation between number of hookahs and carbon monoxide (0.84).

5. DISCUSSION AND CONCLUSION

5.1 Discussion of Research Questions

The study indicates that inhaling ETS from both hookah and smoking establishments may have potential dangers with respect to establishments that do not permit smoking, as the concentration levels of both black carbon and carbon monoxide are significantly higher in hookah and smoking establishments versus non-smoking establishments. The study also shows that while black carbon levels in smoking establishments are significantly higher than in hookah establishments, carbon monoxide levels are significantly higher in hookah establishments than in smoking establishments. This is possibly due to the fact that the smoldering charcoal on a hookah is a source of carbon monoxide. It is important to note that during the monitoring period, two minors were observed in Location B, a hookah establishment.

5.2 Comparison to Previous Research

Previous research has shown elevated concentration levels in both black carbon and carbon monoxide in establishments that permit cigarette smoking and/or hookah smoking, as compared to establishments that do not permit smoking of any kind. This study reports also those findings. Additionally, as with previous research, results of this study demonstrated that levels of indoor air pollution increased with increasing numbers of active hookahs smoked. This study showed a strong correlation between number of hookahs and carbon monoxide concentrations in establishments that permit hookah smoking.

5.3 Study Strengths and Limitations

This study involved several possible limitations that may have exhibited various effects on the integrity of the results and testing procedures. One limitation was the season and/or weather conditions. In adverse weather conditions, there were not as many people in the testing locations, which may not be representative of the number of people typically present at the venue. This study attempted to address this limitation by sampling the monitoring locations during the spring season. All data was collected during the month of April 2014 and April 2016. Another potential limitation was the time of day. This may also serve as a limitation due to proper sample size, especially at the smoking and hookah locations. This study addressed this issue by visiting the monitoring locations during what would be considered “peak times” for the locations, to ensure an appropriate number of patrons. Another probable limitation was instrument functionality, which includes human error and the battery life of the instruments. These factors may affect data logging and recording methods. This study avoided this limitation by ensuring that the instruments were properly charged and programed prior to visiting each location. The procedure itself also served as a limitation. This is due to the fact that instruments had to be placed in a handbag in order to sample in the locations; this aspect could make it difficult to ensure testing integrity. To minimize this limitation, all sampling probes were properly exposed to the air and optimal seating was selected in each monitoring location to ensure access to patrons. Another possible limitation could be the timeframe for instrumentation use. It is necessary to sample each venue more than once. This study attempted to address this limitation by monitoring multiple venues within the same venue type, in order to increase the generalizability and validity of the study. Lastly, other limitations include a small sample size (six monitoring locations) and varying ventilation conditions between the locations. Further studies should include more monitoring locations, and a method for controlling for ventilation conditions at the locations.

5.4 Implications of Findings

The results of this study advance scientific knowledge on air pollution present in hookah smoking and cigarette smoking venues and inform public health advocates and decision makers on smoking policy needs. The study strengthens the argument that local and state policymakers should advocate for the enactment of comprehensive smoke-free laws that include smoking venues of various types. Policymakers have met challenges and barriers in their attempts to develop and enforce smoke-free air laws. The greatest challenge has been resistance from restaurant/bar owners that insist revenue will decrease with the passing of such laws (Melberg & Lund, 2012). There have been numerous studies that suggest that smoke-free laws do not have an adverse economic impact on restaurants or bars (Loomis *et al*., 2013). The results of this study also indicate that smoke-free venues have lower black carbon and carbon monoxide compared to smoking/hookah venues. It also demonstrated the necessity of how full compliance with strict regulations is needed to further improve indoor air quality.

5.5 Recommendations and Prevention Strategies

There are no specifically defined standards or regulations for black carbon under the Indoor Air Quality Guidelines; however, there is an EPA initiative underway in order to regulate black carbon separately from other particulate matter substances under the national ambient air quality standards (NAAQS) (EPA, 2012). Smoking establishments do not have to adhere to the Indoor Air Quality Guidelines for carbon monoxide levels, as long as they do not permit patrons under the age of 18, supporting the need for more stringent and uniform smoke-free regulations in public venues (WHO, 2003). Currently, local, city, and state laws regulate smoke-free policies, and there is a vast need for standardization across these governing regulations. The Food and Drug Administration (FDA) regulates tobacco policies, while indoor air quality is regulated and governed by each individual state's health department (EPA, 2018). Therefore, it will be necessary for these agencies to collaborate to monitor and assess compliance. Federal and state excise taxes on tobacco products can be utilized to support the cost of regular assessment. If more cities and countries adopt these laws, when implemented properly, health benefits worldwide should be seen.

5.6 Conclusions

The World Health Organization Framework Convention on Tobacco Control calls on governments to “protect all persons from exposure to tobacco smoke,” they go on to state that “this protection should be extended, according to Article 8.2, in indoor workplaces, public transport, indoor public places and … other public places” (WHO, 2003). Smoke-free regulations on manufactured and hand-rolled tobacco products such as cigarettes, cigars, and cigarillos (little cigars) has improved indoor air quality and reduced ETS exposure risks in public venues. These regulations may serve as a model for the policy initiative for hookah/waterpipe use in US lounges/restaurants.

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