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Air pollutant concentrations and comfort index in commercial buses within Abeokuta Metropolis, South-Western Nigeria

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Abstract
This study assessed the level of air pollutants and comfort index in public buses from selected parks in Abeokuta metropolis. Sixty commercial buses were randomly selected across the four major motor parks in the city for the monitoring of comfort index (temperature and relative humidity) and air pollutants (carbon monoxide, volatile organic compounds and particulate matter) within one month using low-cost hand-held portable meters. The average temperature and relative humidity ranged between 35.6 – 36.0°C and 57.9 – 62.4% respectively. The average concentrations of in-vehicle air pollutants ranged from 29.8 – 32.7 mg/m^3 (CO), 58.3 – 76.3 μg/m^3 (VOCs), 25.3 – 44.2 μg/m^3 ($PM_{2.5}$) and 108.3 –117.4 (PM_{10}). Significant spatial variations among in-vehicle RH and VOCs were observed across the sampling locations. The Air quality index of air pollutants within the vehicles was rated hazardous (CO), unhealthy ($PM_{2.5}$) and moderate (PM_{10}) across the motor parks. The passengers and drivers exposed to this poor air quality could be at risk of breathing discomfort and other respiratory illnesses, hence the need for specific measures to reduce the air pollutant concentrations within the buses.

Keywords
In-vehicles, Thermal comfort, Air quality, Pollutants, Abeokuta

Introduction

One of the major threats to public health especially in low and middle-income countries (LMICs) is air pollution (Manucci *et al.*, 2017). The functionality of cities regarding their socio-economic activities is largely dependent on mobility (Aworemi *et al.*, 2009). The rise in urbanisation, human activities, and over-reliance on vehicles as a means of mobility has led to an increased volume of traffic resulting in air emissions from different types of vehicles. Over the years, the reliance on fossil fuel in vehicles, inefficient utilization of energy in public transportation, and traffic congestion have contributed to poor quality of air in major cities in Nigeria (Ozcan andCubukcu, 2018). Müller *et al.* (2011) opined that the average time people spend in vehicles daily is more than an hour; hence, drivers and passengers are constantly exposed to varying levels of air pollutants within the vehicle. Air quality in cars is likely to be worse than air quality in other microenvironments such as buildings due to the proximity of passengers to pollution sources (ex-

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haust pipes and interior accessories). The outdoor air pollutants can also infiltrate the microenvironment resulting in the increase of air pollutants in the car cabins and car interior materials (Barnes *et al.* 2018; Xu *et al.* 2016). The interiors of cars comprise seats, floor materials made of rugs and plastics, dashboards, carpet, fabrics, resins and fibres. These components are made up of substances and chemicals that are potential emission sources of volatile organic compounds (VOCs) and are often determined by the variations in meteorological parameters inside the vehicles. Studies have found that unhealthy levels of oxides of nitrogen, sulphur (iv) oxide, carbon monoxide and particulates resulting from the incomplete combustion of fuel and diesel have been observed within vehicles (Grana *et al.*, 2017; Dirks *et al.*, 2018). Acute and chronic exposure of commuters to pollutants inside vehicles could become a risk factor for several illnesses including respiratory diseases, chronic asthma, and malfunctioning of the lungs (European Environment Agency, 2018; Eghomwanre and Oguntoke, 2022). The exposure of commuters to in-car air pollutants including traffic-related air pollutants (TRAPs) above regulatory limits has been linked to dizziness, fatigue, impaired vision and coordination, headaches, and confusion (Wong *et al.*, 2018; Kelly and Fussell, 2019; Xu *et al.*, 2016). The concentrations of pollutants inside vehicles are largely determined by different factors which include ventilation mode, efficacy of in-car cabin air filter, meteorological conditions, nearness to pollutant source and intensity of traffic (Kelly and Fussell, 2019; Moreno *et al.*, 2019). The thermal comfort of passengers inside the vehicles is influenced by different factors (Simeon *et al*, 2016). These factors are indoor air temperature, illumination, humidity, airspeed, activity level and clothing insulation. The variations in these factors can result in thermal discomfort which can disrupt the attention of the driver as well as affect the well-being of passengers (Alahmer *et al.*, 2012). Although numerous studies have been done on traffic-related air pollution in developed countries (Chaney *et al.*, 2017; Grana *et al.*, 2017; Rivas *et al.*, 2017; Dirks *et al.*, 2018). The evidence of heterogeneity of the concentrations of air pollutants in the microenvironment of commercial vehicles in the developed nations provided by literature (Moreno *et al.*, 2019; Onat *et al.*, 2019; Hong, 2019), suggests the need to focus on air quality monitoring in cars to decrease the daily exposure of drivers and passengers to air pollutants. Air quality related studies in Nigeria have largely focused on ambient or roadside environments (Abam and Unachukwu, 2015; Etim, 2016; Nkwocha *et al.*, 2017; Adeyanju and Manohar, 2017; Ogungbe *et al.*, 2019; Eghomwanre et al., 2022). A few studies on the exposure of commuters to air pollutants in vehicles have been carried out in Nigeria (Omagamre *et al.* 2016; Odekanle *et al*, 2017). To contribute to this obvious dearth of literature and knowledge gaps, this study assessed the thermal comfort index and air quality in commercial vehicles within Abeokuta city. This will help provide a comprehensive and empirical database on air pollutant concentrations and assist in intervention studies aimed at reducing air pollution exposures in commercial vehicles in the study area.

Materials and methods

Study area

The study was carried out in Abeokuta, the capital of Ogun state, southwestern Nigeria. The city is located on the central railway advancing from Lagos at approximately 78 km south and within the long-existing road from Lagos to Ibadan City. The mode of transportation in Abeokuta is mainly by road. Road transport is the second most predominant means of transport in the city other than trekking which is mainly for trips of short distances. The public transport sector is also characterized by the use of private vehicles such as taxis, minibuses, tricycles and commercial motorcycles (popularly called Okada). The public transportation situation in the city is informal, uncoordinated and poorly regulated with buses and taxis being the predominant kind of transporttation in the state.

Selection of sampling locations

The sampling was done in the four major parks in the city, located in Adatan, Ashero, Itaoshin and Lafenwa areas. The parks are located along major highways and are dominated by second-hand gasoline and diesel-powered buses that are generally 14-seaters (16 passengers in some cases), without air conditioners, ventilation mainly by windows which are often opened, and seats and floors with rug materials. Sixty vehicles, fifteen from each motor park were randomly selected. In-vehicle measurements were carried out in triplicates at three different points; the back, middle and front seat of the car. Sampling was done daily from 8 am to 12 noon during loading and before the departure of the vehicle from the park for a one month.

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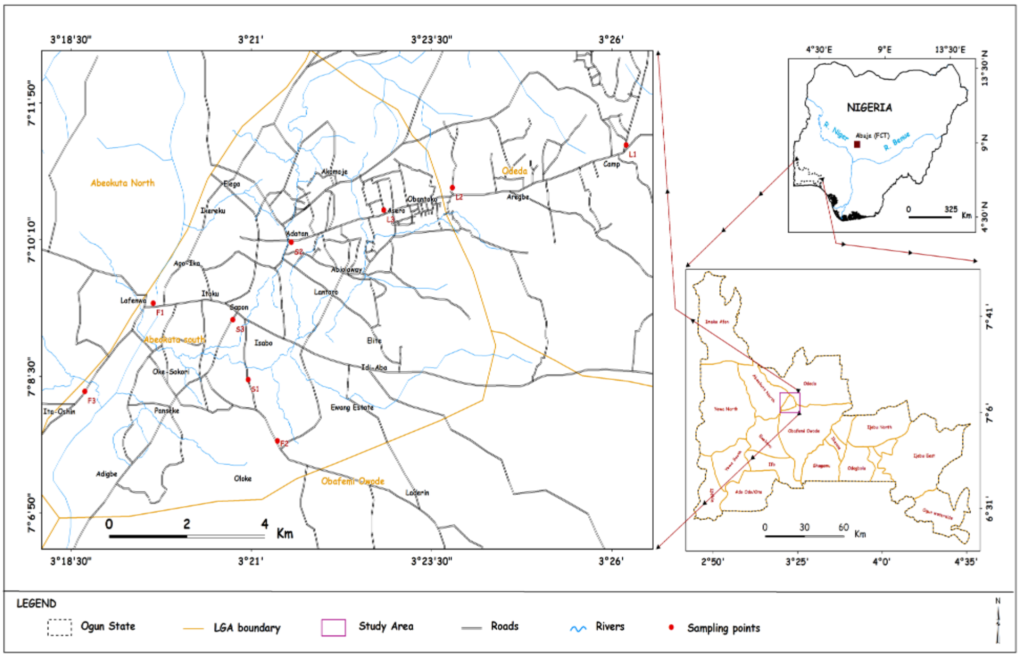

Figure 1
Map of Abeokuta showing the sampling locations

Measurement of comfort parameters

The comfort index measured was temperature and relative humidity. This was done using the WindMate-350 multi-function weather meter with a range and precision of -20 - 60°C, +/- 1°C) temperature and (0 to 100%, +/- 3%) humidity in the selected vehicles. The equipment is a precise and self-calibrating humidity sensor, with a logging function to hold the readings with precise humidity and barometric sensors and precise humidity sensor. It provides accuracy and precision by utilizing the wind vane and digital compass to provide wind measurements at compass points. The average of the measurements obtained was taken and the result was compared with the World Health Organisation indoor air quality standards (WHO, 2010).

In-vehicle air quality measurements

Measurement of air pollutant concentrations was conducted in the selected vehicles in triplicates at three different points using an Aeroqual 500 series portable monitor with a swappable sensor head measuring different pollutants which include; CO, VOC, $PM_{2.5}$ and PM_{10} with detection limits of 0-1233(mg/m^3), 0-5000(µg/m^3) respectively. The sampler is slow vibrating equipment that initialises every 3 minutes before the reading of the selected air parameter. The equipment was calibrated according to the recommendations They were placed at 1.2m above the ground level at each sampling point while the digitally displayed values were recorded as soon as the sampler attained the maximum level. The daily acquired data were used to determine the average concentrations of the measured parameters and compared with the indoor air quality guidelines of the World Health Organisation (WHO, 2010).

Determination of Air Quality Index

The AQI is a tool used for simplifying the interpretation of air quality in a specified location, making it easily comprehensible to the general public. The indices for each air pollutant measured in the vehicles across the sample locations were derived using the USEPA-recommended mathematical functions to compute the AQI (USEPA, 2006). The USEPA guidelines state that the sub-indices for particular pollutants at a monitoring location are determined using the pollutant health breakpoint concentration range and the 24-hour average concentration. The USEPA AQI values represent six categories, viz; Good (0-50), Moderate (51-100), Unhealthy for sensitive individuals (101-150), Unhealthy (151-200), Very unhealthy (201-250), Very unhealthy (251-300) and Hazardous (301-500). The AQI formula used is given in Equation [1]

$$AQI = \frac{Ihigh - Ilow}{BPhigh - BPlow} X\,(Cp - Bplow) + Ilow \qquad [1]$$

where: AQI = Index of the pollutant; Cp = the rounded concentration of pollutant p; BP_{high} = the break-

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point greater or equal to Cp; BP_{low} = the breakpoint less than or equal to Cp; I_{high} = the AQI correspondding to BP_{high}; I_{low} = the AQI corresponding to Bp_{low}

Data Analysis

The data obtained from the sets of measurements were subjected to normality tests using the Kolmogorov-Smirnov method to determine which statistical method would be suitable for the analysis. The descriptive (mean and standard deviation) and non-parametric inferential statistics (Kruskal Wallis) on the SPSS 21.0 version were employed. The concentrations of in-vehicle air pollutants and conform indices were estimated using mean and standard deviation while the variations in the pollutant concentrations across the sample areas were examined using Box and Whiskers plots which is a representation of the distribution of the pollutant concentrations utilizing the lower, upper and interquartile range, minimum and maximum values. The significance of the observed variations in the comfort index parameters and the air pollutant concentrations across the locations was tested using the Kruskal Wallis independent test.

Results and discussion

The result of the normality test using the Kolmogorov -Smirnov method showed that the p-value of the obtained data across the selected locations was less than 0.05 ($p < 0.05$). (Table 1). This implies that the data were not normally distributed.

Table 1. *Normality test for monitored data*

Parameters	Kolmogorov-Smirnov[a] statistic	df	P - Value
TEMP	0.094	160	0.001
RH	0.207	160	0.000
WS	0.231	160	0.000
VOC	0.086	160	0.006
CO	0.145	160	0.000
$PM_{2.5}$	0.166	160	0.000
PM_{10}	0.078	160	0.019

[a]. Lilliefors Significance Correction

Average in-vehicle comfort index and air pollutant concentrations

The comfort indices monitored in vehicles during this study include temperature and relative humidity. The indoor temperature ranged from 35.6 to 36.0°C (Figure 2). The highest in-vehicle temperature was observed in Adatan (35.9°C) while the least was recorded in Ashero motor parks (35.64°C) (Figure 2). The observed temperature in the vehicles across the locations was slightly above the ASHRAE temperature range of 23°C - 26°C (ASHRAE, 2013). The observed increase in temperature of the vehicles could be attributed to various factors; the availability of space, floor seat material inside the vehicle, air conditioning systems and prevailing outdoor temperature. In-vehicle temperature above the regulatory

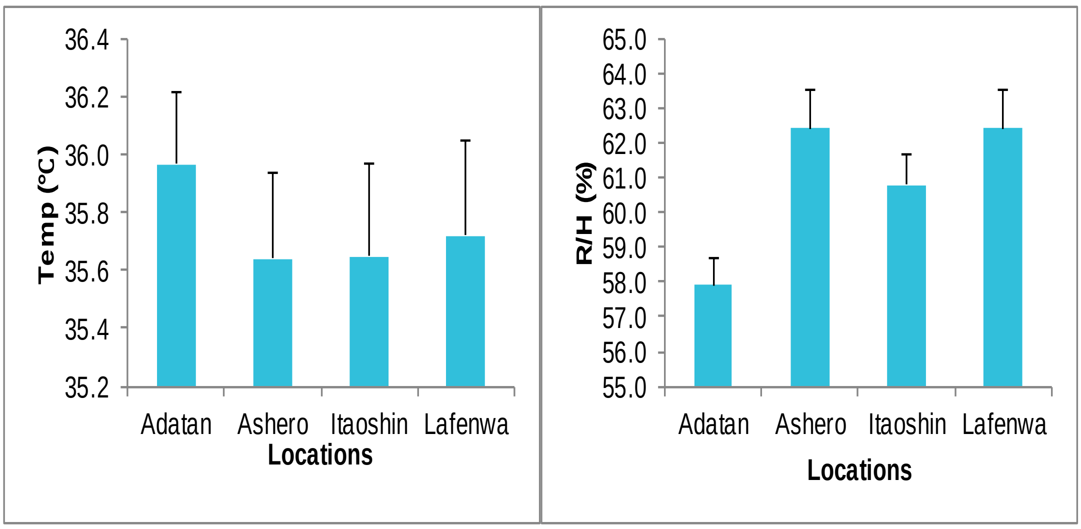

Figure 2 Mean levels of in-vehicle temperature and relative humidity

threshold could lead to thermal discomfort which can distract the focus of the driver and result in different health outcomes such as stiffness and shortness of breath in the passengers (Akanmu *et al.*, 2020). The

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highest mean relative humidity (62.4%) in the vehicles was observed in Ashero and Lafenwa parks while Vehicles in Adatan had the lowest RH values of 57.90% (Figure 2). According to ASHRAE (2013), indoor relative humidity within the range of 30 – 60% does not influence thermal comfort. This study showed that monitored vehicles in 75% of the sample locations had an RH higher than 60%. The Increased in-vehicle RH could prevent the evaporation of sweat and result in a sultry weather sensation, hence discomfort to the passengers (Fountain *et al.*, 1999; Zhou, 2013). The average concentrations of air pollutants measurements in the selected buses across the sample locations are also shown in Figure 3. The concentrations of carbon monoxide varied from 29.79 to 32.71 mg/m^3 throughout the sites. The highest CO value was recorded at Itaoshin motor parks while the least was measured in the Lafenwa area. The levels of in-vehicle CO measured in this work were higher than the reports of Esber *et al.* (2007) and Dirks *et al.* (2108) who investigated the concentrations of carbon monoxide in cars. The increased levels of CO observed in buses could be attributed to the larger cabin volume in buses compared to cars and background CO pollution from the various buses at the motor park. Sood *et al.* (2014) opined that the larger the volume of the cabin the higher the pollutant concentrations in the cabin. Omagamre *et al.* (2016) also reported lower concentrations of carbon monoxide of 8.99 to 10.66 ppm in both gasoline and diesel engine buses in Benin City and associated it with the infiltration of outdoor air through the opened windows that dilute the pollutant concentration while the buses were in motion. The concentrations of carbon monoxide observed in the study were also in contrast with the reports of Odekanle *et al.* (2017) who reported an average CO level of 23.68ppm in lower levels of CO inside the Bus Rapid Transit in Lagos, Nigeria. The authors attributed the lower level of CO to the configuration of the bus which shields the commuters

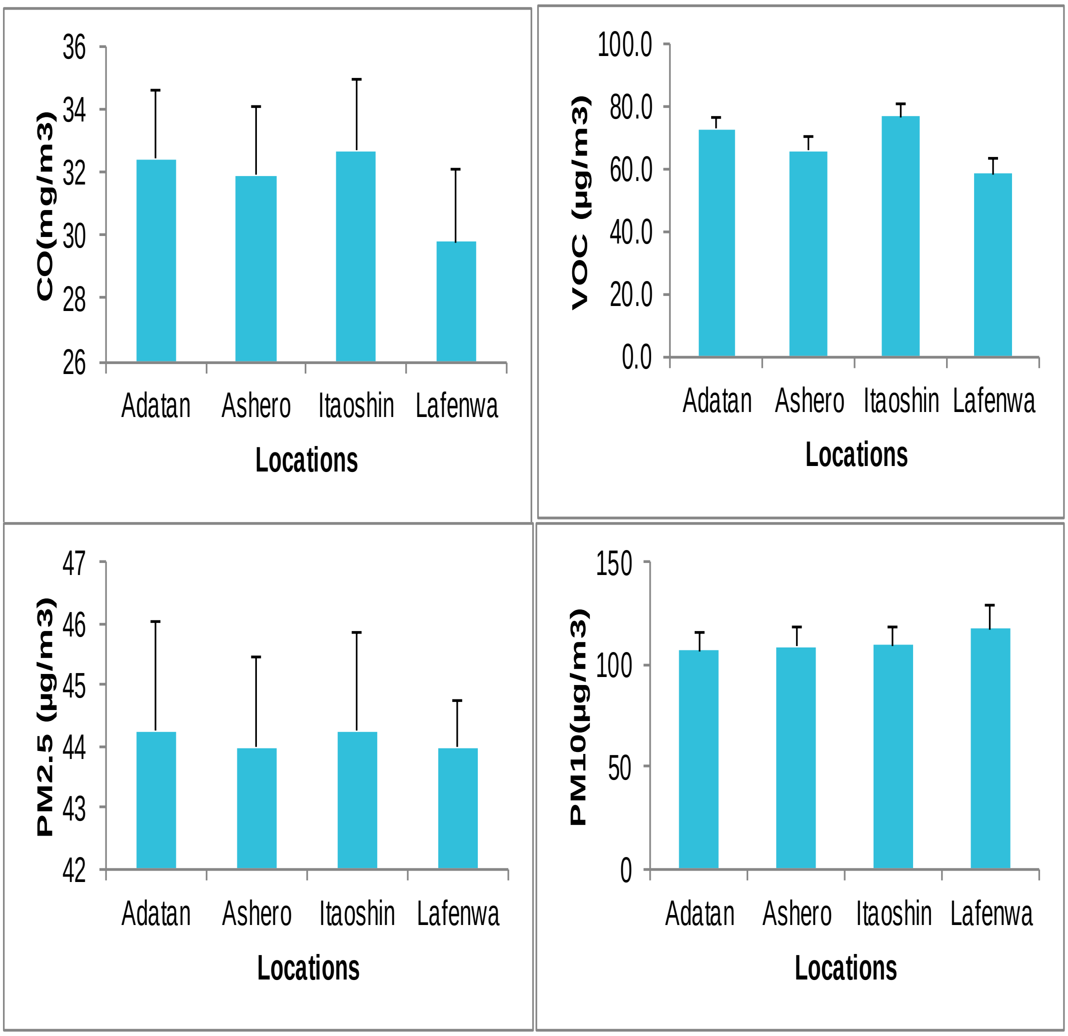

Figure 3
Mean concentration of in-vehicle air pollutants

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from the pollutants from the outdoors and exhaust pipes. The carbon monoxide concentrations were four times higher than the recommended 7mg/m^3 by the World Health Organisation (WHO, 2010). Short-term expo-sure to increased levels of CO especially in a confined environment could cause impaired vision, headache dizziness, nausea, tiredness and distraction (Esber *et al*, 2007). These health effects could result in the di-scomfort of passengers and become hazardous to dri-vers and other commuters (Weichenthal *et al*., 2015). The concentrations of VOCs in the buses varied between 58.31 and 76.73 µg/m^3 across the locations (Figure 3). The observed values of in-vehicle VOCs were below the regulatory threshold of 160µg/m^3 of the Federal Ministry of Environment (FMEnv, 1999). Potential sources of VOCs inside vehicles are the interiors of buses which include dashboards, floors and seats made from VOC-releasing materials or chemicals such as plastics, rubber, fabrics, resins and fibres. Jo and Park (1999) opined that in vehicles VOC concentrations could also emanate from the idling hot engine and then infiltrate the interior of the vehicle. Long-term exposure to volatile organic compounds within enclosed spaces could result in health effects such as irritation, feelings of discomfort, headache and possible neurotoxic effects (Faber and Brodzik, 2016). The measured $PM_{2.5}$ and PM_{10} concentrations varied between 25.3 to 44.2 and 108.3 to 117.4 µg/m^3 respectively. The highest $PM_{2.5}$ level was recorded in buses at Adatan while the buses at Lafenwa have the highest concentrations of PM_{10}. The average in-vehicle concentrations of particulates across the sampling locations were higher than the indoor WHO-recommended exposure guideline of 25 and 50 µg/m^3 (WHO, 2010). The high level of in-vehicle particulates in this study could be due to the infiltration of outdoor particulate emissions resulting from exhaust pipe fumes occasioned by the intermittent opening and closing of windows in the non-AC buses. Alamddine *et al.* (2016) reported that there was a strong link between outdoor PM and in-vehicle PM concentrations in Lebanon. This study is consistent with Omagamre *et al.* (2016) who observed an average concentration of 115.4 µg/m^3 in gasoline-fueled buses in Benin City. Few investigations outside Nigeria reported that increased levels of in-vehicle PM were due to cabin ventilation and leakages (Knibbs and de Dear, 2010; Zuurbier *et al*., 2010). Riediker *et al.* (2004) observed that in-vehicle exposure to high levels of $PM_{2.5}$ may result in patho-physiological-related changes involving coagulation, inflammation and cardiac rhythm.

Spatial variations of In-vehicle comfort and air quality parameters

The box and whisker plots of the spatial distribution of mean concentrations of in-vehicle pollutants at the four sampling locations are presented in Figure 4. The result revealed the median, (black line within the box), while the 25th, 75th percentiles, the minimum and maximum concentration of the pollutants were also shown. The indoor temperature of buses at Itaoshin had the highest interquartile range and thus the highest temperature variation occurred at the Itaoshin site. However, the variations in temperature across sampling locations were not significant ($p = 1.000$). The variations in the in-vehicle relative humidity were highest in Ashero with the highest interquartile range. There was a significant variation in the relative humidity across the sampling locations ($P = 0.004$). However, the Duncan test revealed that the significant variation only occurred at Adatan. This may be attributed to the differences in the level of ventilation in the various buses at the location. The highest variation of in-vehicle CO levels occurred at Itaoshin and Adatan. This could be due to the emissions from the various buses at both parks. Generally, there were no significant differences in CO across the sampling locations ($p = 0.987$). The interquartile range of in-vehicle VOCs was highest in Ashero. The variation in VOCs across sampling locations was significant ($p = 0.012$). The Duncan test of variability revealed that the variation occurred at Lafenwa and Itaoshin. The differences in VOC concentration could be due to the relative age of the buses. The concentrations of VOCs from chemical components of air inside vehicles could decrease with time. The chemical composition of indoor air in vehicles varied for new vehicles when compared to old ones (Chien, 2007). There were no significant variations ($p = 0.999, 0.802$) in $PM_{2.5}$ and PM_{10} values across most of the sampling locations. However, greater variability was observed at Lafenwa with the highest interquartile range for both PM fractions. The variations in PM concentrations across the location could be due to the varying degree of pollution arising from the gasoline engine emission, or emissions from nearby vehicles in the park. Behrentz *et al.* (2004) also opined that the variability of particulate pollution in vehicles could be attributed to the age, type, and ventilation inlet positions in vehicles.

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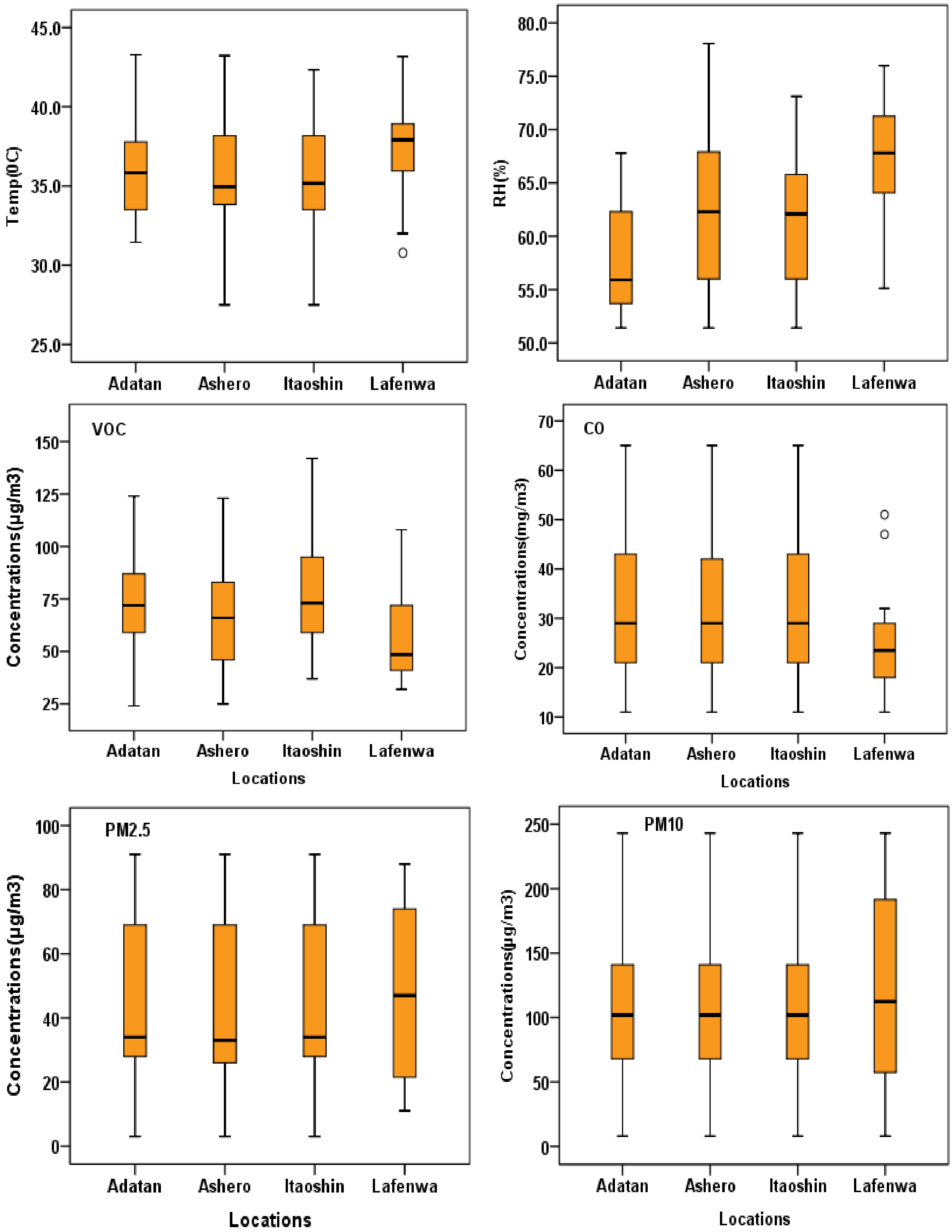

Figure 4. *Spatial variations of meteorological and air quality parameters across the study sites*

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Air quality index of in-vehicle air pollutants

The AQI for air pollutants inside the vehicles across the locations is shown in Table 2. The AQI values of in-vehicle CO ranged between 296 and 323, and it falls under the hazardous category in all the locations except at Lafenwa where it was rated unhealthy. This is of great concern as passengers and drivers inside the vehicles could be exposed to hazardous levels of CO. Levitt and Levitt. (2015) reported that exposure to elevated levels of CO can react with haemoglobin forming carboxyl haemoglobin resulting in hypoxia and cardiovascular disorders in exposed individuals. Other clinical manifestations of inhaled CO in exposed individuals are headache, fatigue, nausea and dizziness (Eghomwanre *et al*, 2022; Jones *et al.*, 2002). The AQI status of $PM_{2.5}$ was unhealthy, while that of PM_{10} was moderate across the sampling locations. Exposure of individuals to unhealthy concentrations of particulates could result in respiratory health problems including difficulty in breathing, asthma, chronic obstructive pulmonary diseases (COPD) and cancer (Eghomwanre et al., 2022; Ristovski *et al.*, 2011).

Pollutants/locations	CO	$PM_{2.5}$	PM_{10}
Adatan	320	108	76
Ashero	315	108	77
Itaoshin	323	108	78
Lafenwa	296	108	82
AQI colour code	Hazardous (301-400)	Unhealthy (101-150)	Moderate (50-100)

Table 2
AQI of air pollutants and associated level of health risks

Conclusions

The study revealed that the comfort indices were above the recommended thermal standard levels for indoor environments. Although, the effects of increased thermal comfort indices on human health remain unclear as a result of limited investigations on the subject, however, the temperature and relative humidity of the vehicles should be within the limits of thermal standards. Additionally, the observed concentrations of CO, $PM_{2.5}$ and PM_{10} in the monitored buses were above the WHO recommended standards for exposures in indoor environments, suggesting that the drivers and passengers could be at risk of being exposed to unhealthy levels of air pollutants and their related health effects. The calculated AQI further revealed that the air quality within the buses was poor and could pose the risk of respiratory-related health problems to exposed individuals. Based on this finding; we may suggest specific measures for reducing the level of air pollutant concentrations such as improving fuel quality, replacing old engines with upgraded ones and use of face masks by passengers on buses. In addition, routine air quality monitoring and air quality regulations in the public transport sector in the study area should be given priority through exposure-based policy formulations.

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