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Variability of Meteorological Factors on In-cabin and Pedestrians Exposures to CO and VOC in South-west Nigeria

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Abstract One of the major environmental challenges in Nigerian big cities is air pollution. This study examined the influence of meteorological factors on in-cabin and pedestrian exposures to gaseous pollutants in various modes of transportation in Lagos City, South West Nigeria in other to establish their linear relationship. The pollutants were CO, VOCs, while the meteorological factors were wind, temperature and relative humidity. Measurements were made inside four major modes of transportation in the city: cars, buses, Bus Rapid Transit (BRT) and walking for CO and VOC. Measurements were done for each mode twice a day (morning and afternoon) between November 3, 2013 and January 6, 2014 (except on Sundays). The relationship between the meteorological parameters and the pollutants' concentrations was obtained using multiple linear regression model. The result and analysis revealed that CO and VOCs have negative correlations with temperature in all modes of transportation selected while they have positive correlations with relative humidity. It was also revealed that there is statistically meaningful difference between CO concentrations and temperature.

Keywords: *commuters, air quality, pedestrian, meteorological factors, CO, VOC*

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1. Introduction

Air pollution is a global problem being compounded by increasing anthropogenic activities: speedy development, rapid industrialization, transportation, high dependence on fossil fuel consumption, increasing global power needs [14] and this has become a great concern for both developed and developing countries. The temporal variation of concentration of pollutant throughout the day varies with the influence of local wind parameters such as direction, speed and other meteorological aspects [14]. Reference [14] also observed that changing patterns of vehicular traffic and industrial activities also act as a factor for variation in pollution levels.

Globally, traffic-related pollution constitutes about 90-95% of the ambient CO levels, 80-90% NO_x, hydrocarbon and particulate matter [28]. Reference [31] revealed that transportation sources accounted for about 77% of CO levels, 80-90% of NO_x, 36% of VOC and 22% of particulate matter. Transportation, though one of the major components in modern life, it has both positive and adverse effect on human health.

Research in recent decades consistently indicates that air pollution from transport sources has adverse effects on human health outcomes including mortality, morbidity and hospital admission [7,10,20]. Concentrations of the pollutants PM_{25}, CO and benzene are indicators of health effects of pollution originating from inefficient combustion [13]. Reference [32] found that low environmental CO is associated with reduced risk of daily Respiratory Tract Infections hospitalizations. The air people breathe while in transportation is particularly unsafe due to the high concentrations of carbon monoxide (CO), suspended particles (PM_{10} and $PM_{2.5}$) and volatile organic compounds [34].

Several studies suggest that exposure to particulate matter (PM_{10} and $PM_{2.5}$) air pollution is associated with respiratory and cardiovascular diseases and lung cancer [9,27]. CO has strong affinity for combining with the hemoglobin of the blood; hence it reduces the hemoglobin available to carry oxygen to body tissue [15]. VOCs, apart from being active in the formation of photochemical smog ground level ozone production, they are also recognized as being carcinogenic [3]. In Nigeria, much attention is usually on general industrial pollution with little focus on the damage caused by pollution from mobile transportation source [16]. Generally, few people are concerned about the nature of air quality inside automobile. If their thoughts turn to the subject at all, they are most likely to consider it as an outdoor problem. It is thought that most people receive a significant proportion of their daily air pollution dose while commuting to work, whether this be walking, cycling, travelling by car or public transport [11]. This is because commuting journeys inevitably follow high air pollution corridors associated with roadways. Vehicle emissions can be labeled as one of the most important source for some pollutants of great concern such as carbon monoxide, nitrogen dioxide, volatile organic compounds (VOCs) and particulate matter The city motored vehicle fleet include a high percentage of old cars and buses emitting a harmful air pollutants. In transportation sector, gasoline -burning cars, trucks and buses are the major sources of carbon monoxide CO [31]. According to [31], diesel buses and trucks are the main sources of SO_2 and NO_x, while both diesel and gasoline vehicles emit suspended particulates matter and $PM_{10.}$

The urban climate and air pollution are connected in several ways. Reference [23] investigated the association between rainfall and air quality and concluded that rainfall has washout effect on particulate matter. Apart from topography, climatic parameters such as stability of the near-surface atmosphere, wind direction, and wind speed govern the dispersion of air pollution. Although in different part of the world, various studies have investigated the relationships between meteorological parameters and some air pollutants such as ozone [5], [8], [22], SO_2 [18]), NO_2 [26]; there have been no studies of exposure to air pollutants during transport in Nigeria and the effects of meteorological parameters. Reference [17] investigated the influence of meteorological conditions on PM_{10} concentrations in kathmandu valley, India and concluded that wind speed and atmospheric pressure inducing increment of average PM_{10} concentration in Kathmandu Valley.

Previous studies revealed that exposure level to air pollutants in traffic microenvironment is influenced by transportation mode [4,19]; cabin ventilation [6,21] meteorological parameter [19], route, fuel type, filtration deposition and Ultrafine Particle penetration [21]. Wind speed/direction, seasonal variation, precipitation, temperature, humidity and sea spray can all influence pollutant levels [4,17,25]. According to [30], Temperature and rainfall are the two parameters which affect the concentration of gaseous pollutant mostly. The goal of this study is to assess personal exposure to CO and VOCs in various modes on transport in Lagos City, Nigeria as influenced by wind, temperature and relative humidity. The scope of this study is limited to the investigation of linear relationship between the gaseous pollutants' concentrations and the meteorological factors. Understanding the interaction between these air pollutants and meteorology parameters can be a valuable tool for urban planners to mitigate negative effects of air pollution.

2. Materials and Methods

2.1. Description of the Study Area

This study was conducted in Lagos city, Lagos State in Southwest region of Nigeria (Figure 1). Lagos is Nigeria's main commercial centre, with more than 70 percent of the nation's industries and economic activities carried out there, which makes it the most economically important state of the country [29] . It is one of the most important and densely populated cities in Nigeria with pollution problem. The city is also important to the rest of West Africa as a leading regional port and manufacturing centre with the highest number of multinational companies [1]. Lagos is located on latitude 6^0 22^l and 6^0 42^l North and longitude 2^0 42^l and 3^0 22^l East and has over 224 vehicles per kilometer as against 15 vehicles per kilometer in other states in Nigeria [2], hence heavy traffic congestion is experienced by over 10 million commuters on its roads on daily basis. The roadways selected for this study were representative of typical commercial, industrial and residential areas of the city Figure 2 shows the traffic nature in two of the selected routes. The major modes of transportation in Lagos city are bus, car, Bus Rapid Transit (BRT) system... The average journey time on each of the selected routed ranges from 30-45 minutes.

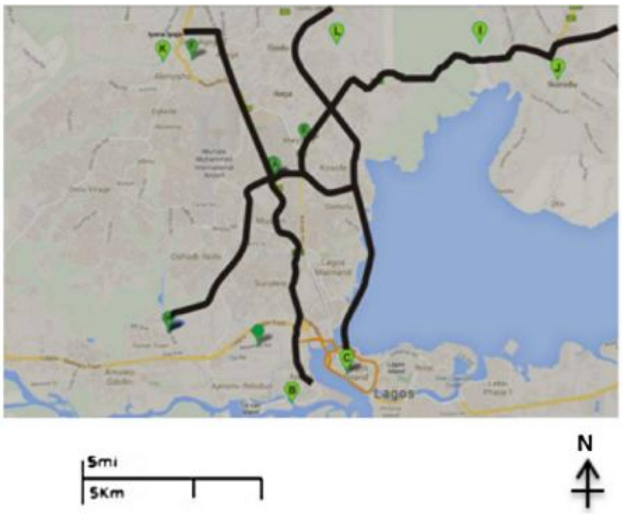

Figure 1. Map of Lagos City showing the selected routes [25]

Figure 2. Typical Traffic congestion in Lagos city [25]

2.2. Materials

In this study, Carbon monoxide (CO) and Volatile organic compounds (VOCs) were measured using the MultiRAE Plus Multi-Gas Monitor. The monitor combines a PID (Photoionization Detector) with sampling pump having a detection range of 0-2000 ppm (measurement for VOC) and 0.1 resolution. It is handheld, portable and Lithium ion (Li-ion) battery operated with a strong, built- in sample pump which draws up air up to 100 feet (30m) horizontally and vertically. The device has relative humidity, wind speed and temperature sensors, and all collected data are stored in the instrument's memory. During the field study, weather parameters (temperature and relative humidity) were recorded with the concentrations of the gaseous pollutants. To measure, it is switched on in the environment of interest and the measured concentrations of the gaseous pollutant read directly on its screen with backlight configuration.

All measurements were taken on each of the pre-determined six routes (as stated above) in Lagos during the morning and afternoon commuting periods for people going by car, bus, and Bus Transit (BRT) vehicles using the equipment described in section above. Four researchers (each per mode of transport) were engaged to simultaneously measure the concentrations CO and VOC on the selected routes (the routes are shown on the map with thick black lines) in the city during the morning and afternoon commuting periods for people going by car, bus, BRT vehicles and walking using the equipment described in the section above. All the researchers attended a training session covering the operation of equipment and the schedule of the study. The measurements were taken during between November 3, 2013 and January 6, 2014 (except on Sundays).

2.3. Methodology

2.3.1. Method of Sample Collection

Samplings were done twice each day: between 07:00 and 10:00 am as well as between 1:00 and 3:00 pm. Measurements were made at both roadway directions while commuting in bus, car, Bus Rapid Transit (BRT) as well as for pedestrians. The pollutants monitoring scheme was as follows: First, in the morning, the vehicles were boarded at the pre-determined starting point and the monitors were switched on. At the final destination, the monitors were switched off. For each route, when the vehicles moved in the opposite direction, the monitors were switched on again. These procedures were also repeated in the afternoon (between1:00 and 3.00pm). Pedestrian exposure for a minimum of 30 min on each route was measured. The modes of transport used for this study were not air conditioned hence in all the modes of transport, windows were kept open and there was no air conditioning system. Car and bus were powered by petrol while BRT was powered by diesel. Smoking was prohibited in all public transport modes in this region, hence nobody was found to violate this during the sampling period. Apart from transport, the other source of CO is from occasional industrial burning of petrol or diesel fuel by electricity generating plant. However, the plants are far from the main roads were the measurements were made The Statistical Package for Social Science (SPSS) program 17.0 was then used for the statistical analysis and testing of the results.

3. Results and Discussion

The descriptive statistics of the pollutants' average concentrations and meteorological factors in various modes of transportation is as shown (Table 1). Forty seven measurements were obtained for both CO and VOC. The levels of CO for the selected modes of transport ranged between 2.93 and 39.78ppm and the highest mean concentration was observed inside car (29.94± 5.57 ppm) VOC concentrations for the selected modes of transport ranged between 0.00 and 1.12ppm, with highest average also recorded in car(0.63± 0.26ppm). The ranges of relative humidity, wind speed and relative temperature were between 24.10 and 62.30%, 3.80 and 6.90m/s and 26.30 and 40.0℃ respectively.

Table 1. Descriptive Statistics for the Pollutants and Meteorological Factors in Various modes Modes

	RH(5%)	WS(m/s)	TMP(^{0}C)	CO(ppm)	VOC(ppm)
BUS					
Mean	33.83	4.74	31.8	20.63	0.22
SD	5.28	0.97	4.13	5.70	0.05
Max	42.10	6.90	38.80	26.96	0.22
Min	24.70	3.80	26.30	12.65	0.18
CAR					
Mean	32.54	4.74	32.53	29.94	0.63
SD	5.46	0.97	4.15	5.57	0.22
Max	40.10	6.90	40.00	39.78	1.12
Min	24.10	3.80	28.00	2.93	0.29
BRT					
Mean	43.50	4.74	32.45	13.04	0.23
SD	11.29	0.97	3.61	2.23	0.07
Max	62.30	6.90	38.90	15.67	0.28
Min	24.20	3.80	28.20	9.91	0..15
WLK					
Mean	40.10.	4.74	7.84	7.84	0.07
SD	9.46	0.97	7.84	1.83	0.04
Max	60.30	6.90	10.32	10.32	0.09
Min	30.00	3.80	4.40	4.40	0.00

RH=Relative Humidity; WS=Wind Speed; TMP= Temperature; SD= Standard Deviation; Max= Maximum; Min= Minimum, WLK=Walking.

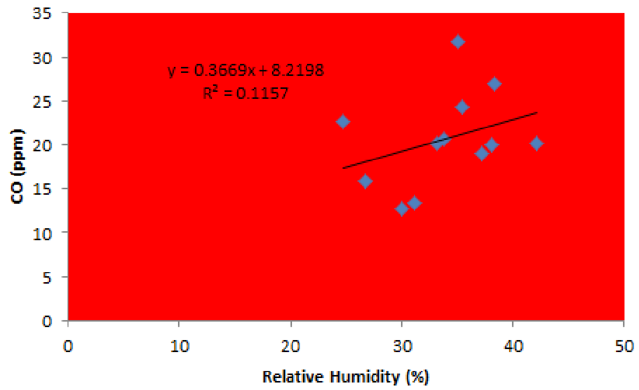

Figure 3. Correlation between CO eexposure levels and relative humidity inside Bus

Table 2. Model Summary and Parameter Estimate

Mode	Dep. Var.	Ind. Var.	R^2	F	df_1	df_2	Sig.
BUS	RH	CO	0.1157	1.178	1	47	0.306
		VOC	0.2424	2.880	1	47	0.124
	WS	CO	-0.1060	1.068	1	47	0.328
		VOC	0.0155	0.123	1	47	0.734
	TMP	CO	-0.5682	11.840	1	47	0.007*
		VOC	-0.1484	1.569	1	47	0.242
CAR	RH	CO	0.0922	0.903	1	47	0.368
		VOC	0.0587	0.562	1	47	0.473
	WS	CO	-0.0011	0.100	1	47	0.922
		VOC	-0.0790	0.772	1	47	0.403
	TM	CO	-0.4380	7.013	1	47	0.027*
		VOC	-0.3248	4.330	1	47	0.067
BRT	RH	CO	0.3498	4.842	1	47	0.055
		VOC	0.0007	0.006	1	47	0.939
	WS	CO	-0.0019	0.170	1	47	0.899
		VOC	-0.0833	0.817	1	47	0.390
	TM	CO	-0.8.533	52.354	1	47	0.000*
		VOC	-0.0898	0.887	1	47	0.371
WLK	RH	CO	0.0072	3.798	1	47	0.083
		VOC	0.7097	22.007	1	47	0.001*
	WS	CO	0.2968	0.065	1	47	0.804
		VOC	0.0159	0.145	1	47	0.712
	TM	CO	-0.4845	8.458	1	47	0.017
		VOC	-0.3946	5.866	1	47	0.038*

Dep Var=Dependent Variable, Ind Var.= Independent Variable, RH=Relative humidity, WS= wind speed, TM=Temperature.

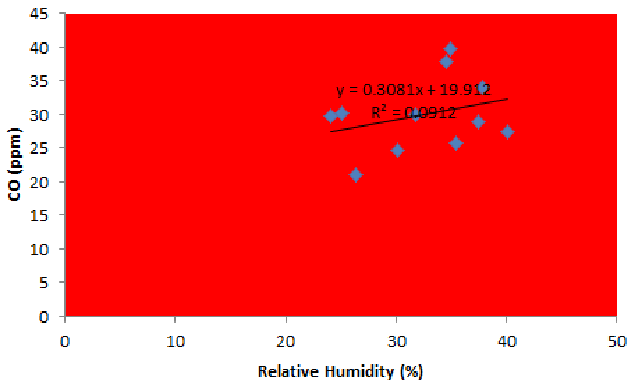

Figure 4. Correlation between CO eexposure levels and relative humidity inside Car

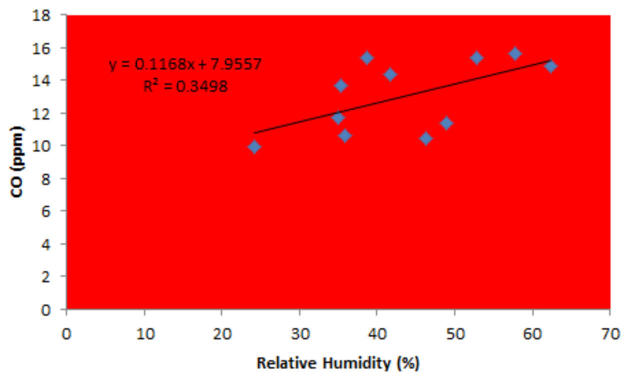

Figure 5. Correlation between CO exposure levels and relative humidity inside BRT

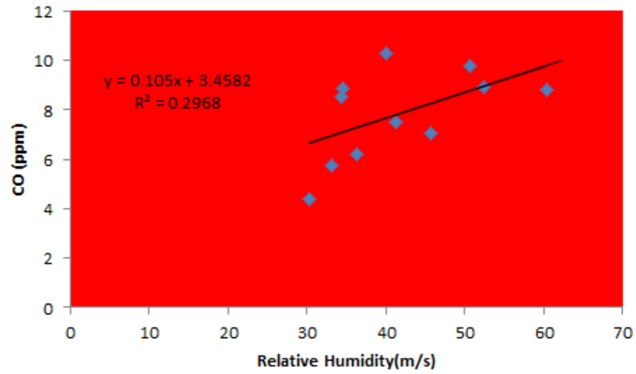

Figure 6. Correlation between CO exposure levels and relative humidity for walking

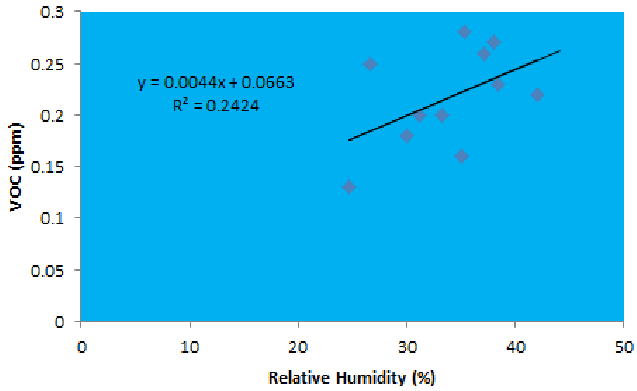

Figure 7. Correlation between VOC exposure levels and relative humidity inside Bus

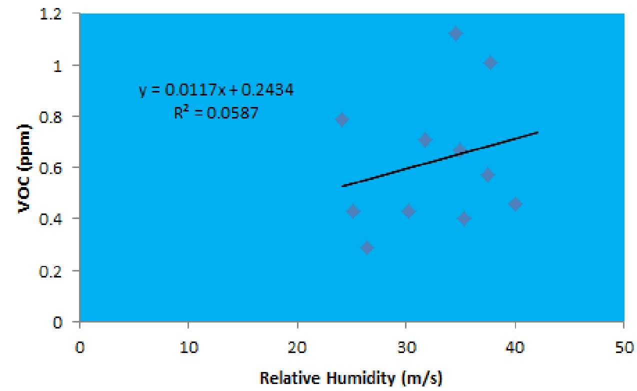

Figure 8. Correlation between VOC exposure levels and relative humidity inside Car

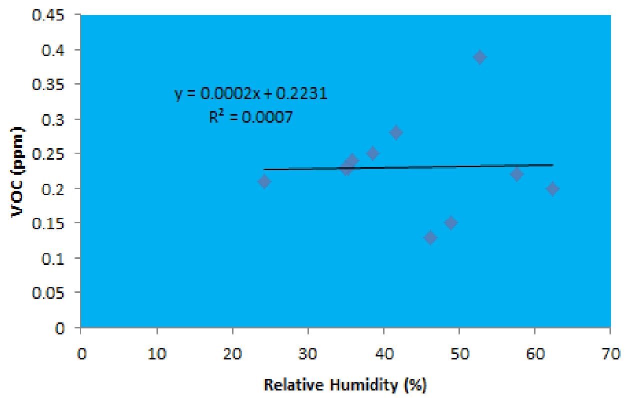

Figure 9. Correlation between VOC exposure levels and relative humidity inside BRT

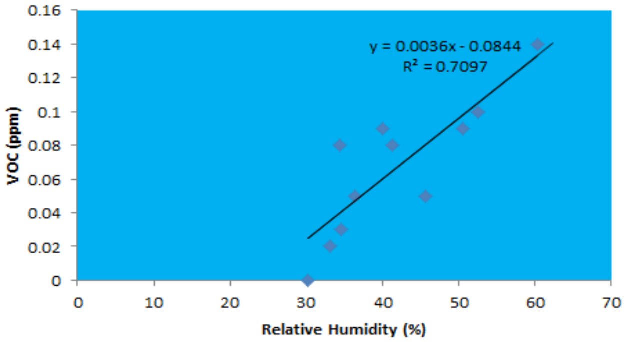

Figure 10. Correlation between VOC exposure levels and relative humidity inside walking

The model summary and parameter estimates of the concentrations of the gaseous pollutants and the meteorological factors inside each mode of transport are shown in Table 2. The effects of relative humidity, wind speed and temperature were investigated and presented in Figures 3-12. As shown in Figures 3-6, CO concentrations and relative humidity showed very weak correlation for bus and car (0.0922 for bus and 0.1157 car), while weak correlation was observed for BRT (0.3498) and there is almost no correlation between CO concentration and relative humidity for those walking (0.0072). The statistical significance of CO concentrations and relative humidity was evaluated by Student's t-test, and no statistically meaningful difference was observed ($p>0.05$). Similarly,as shown in Figures 7-10, weak correlations were observed between VOC and relative humidity inside bus (0.2424), very weak for car (0.0587) and strong correlation for those walking (0.7097). Statistically significant difference was observed between VOC concentration and relative humidity for those walking ($p<0.05$) as shown on Table 2.

According to Figure 3 – Figure 10, when relative humidity increased, CO and VOC concentrations increased, as positive correlations were observed in all modes of transportation except for VOC inside BRT (Figure 9) where negative correlation was observed. Reference [30] observed negative correlation between these gaseous pollutants and relative humidity, though the report was based on ambient air and not in-cabin.

Wind speed has weak correlations with concentrations of CO and VOC in all modes of transportation (CO: -0.1060 for bus, -0.0011 for car, -0.0019 for BRT and 0.2968 for walking; VOC: 0.0155 for bus, -0.0790 for car, -0.0833 for BRT and 0.159 for walking). Except for those walking, CO and VOC have negative correlation with wind speed in all modes of transportation (Figure 11 - Figure 18). This implies, as the wind speed increases, pedestrians at the curbside experience low quantity of these gaseous pollutant as much of them would have been diluted e.g CO converted to CO_2 No statistically significant differences were between the wind speed and these pollutants' concentrations.

Carbon monoxide concentrations were observed to have negative moderate correlation with temperature inside bus, car and for those walking as shown in Figure 19 – Figure 21 (R^2=-0.5682, -0.4380 and -0.4845 respectively). CO has strong negative correlation with temperature inside BRT (-0.8533). For all modes of transportation, there is statistically meaningful difference between CO concentrations and temperature ($p<0.05$), meaning that exposure to CO concentration is temperature dependent This agreed with the study reported by [30]. VOC shows very weak correlation with temperature inside bus and BRT (-0.1484 and -0.0.0898 respectively), while weak correlations were observed for car commuters and those walking (-0.3248 and -0.3946). No statistical significant difference was found between VOC concentration and temperature.

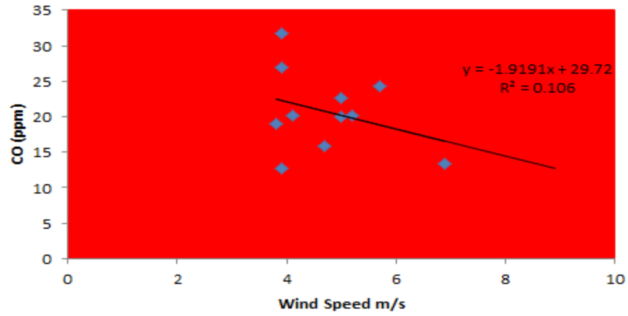

Figure 11. Correlation between CO exposure levels and wind speed inside Bus

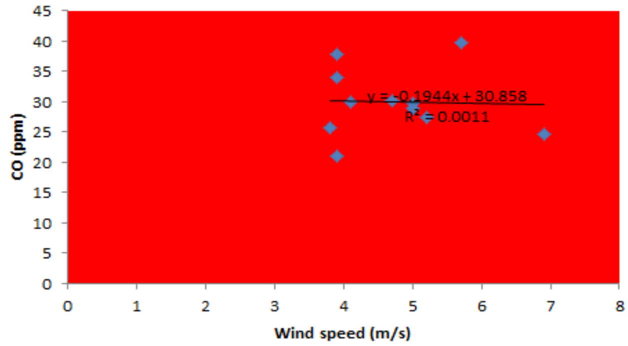

Figure 12. Correlation between CO exposure levels and wind speed inside Car

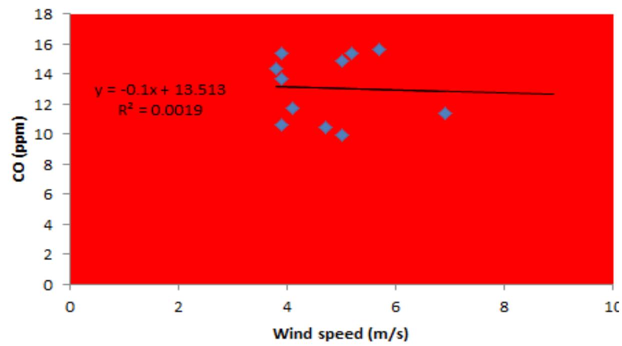

Figure 13. Correlation between CO exposure levels and wind speed inside BRT

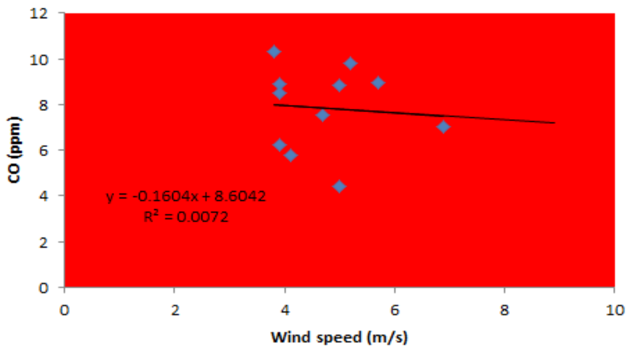

Figure 14. Correlation between CO exposure levels and wind speed for walking

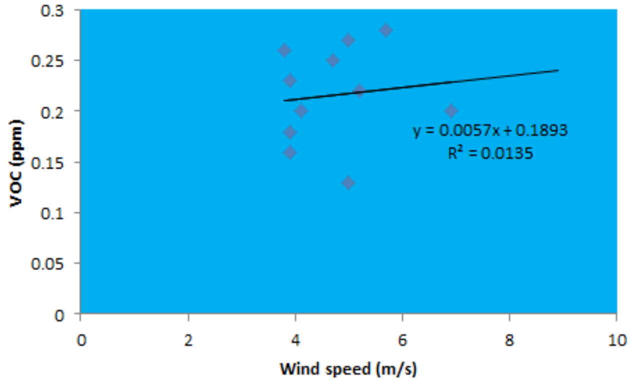

Figure 15. Correlation between VOC exposure levels and wind speed inside Bus

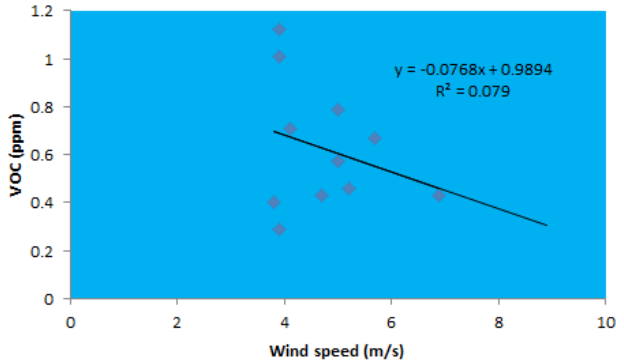

Figure 16. Correlation between VOC exposure levels and wind speed inside Car

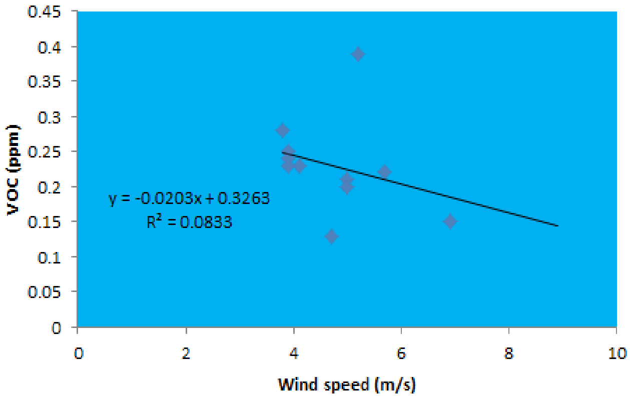

Figure 17. Correlation between VOC exposure levels and wind speed inside BRT

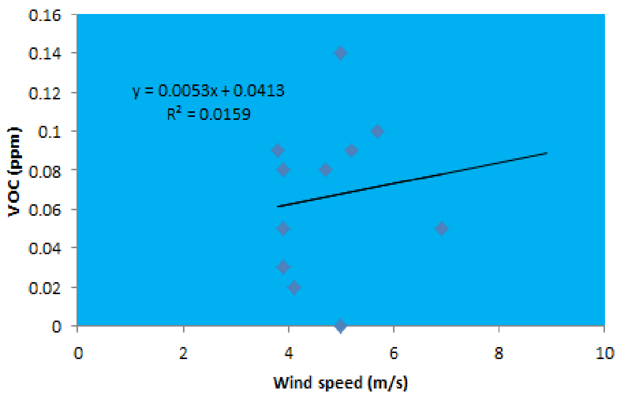

Figure 18. Correlation between VOC exposure levels and wind speed for walking

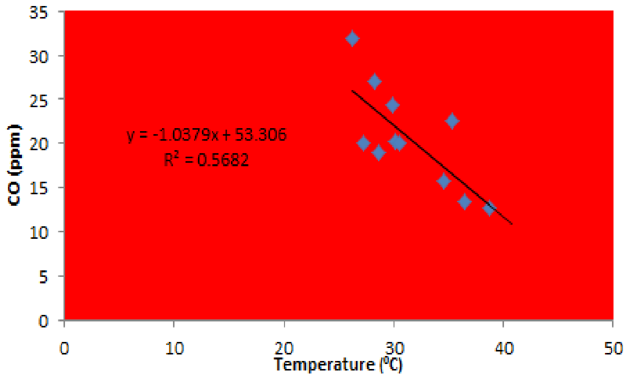

Figure 19. Correlation between CO exposure levels and temperature inside Bus

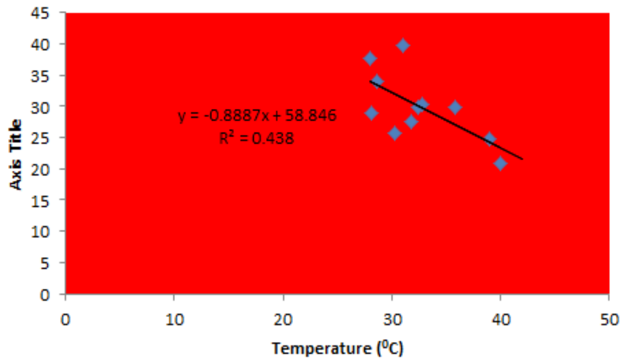

Figure 20. Correlation between CO exposure levels and temperature for walking

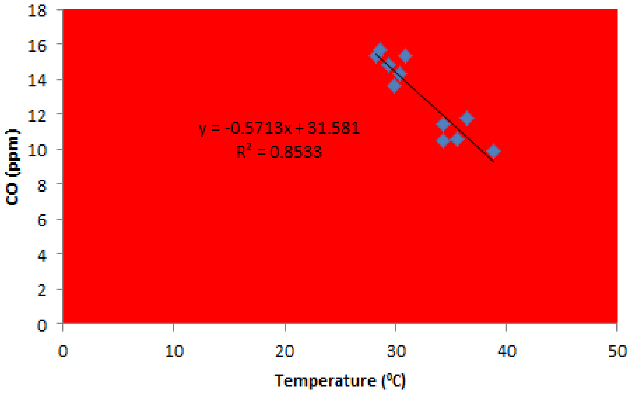

Figure 21. Correlation between CO exposure levels and temperature inside BRT

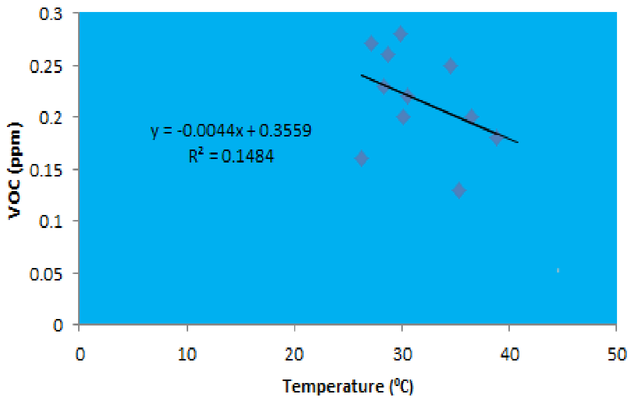

Figure 22. Correlation between VOC exposure levels and temperature inside bus

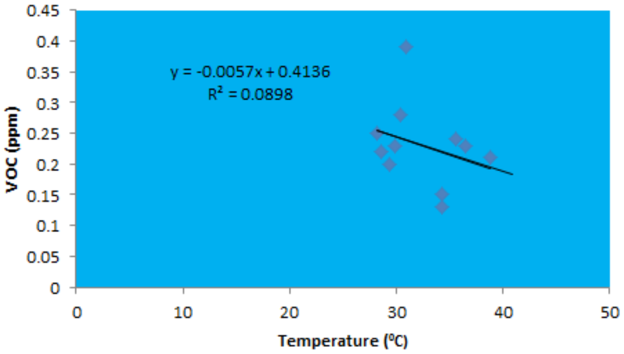

Figure 23. Correlation between VOC exposure levels and temperature inside BRT

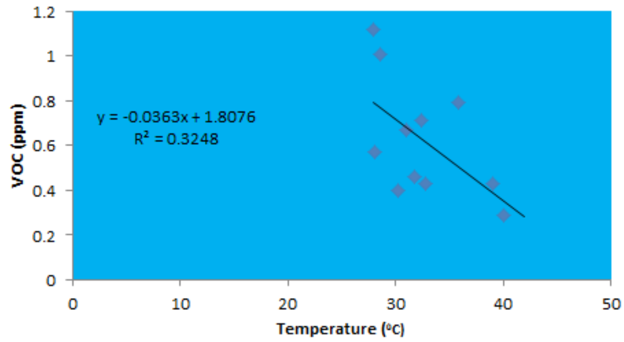

Figure 24. Correlation between VOC exposure levels and temperature inside Car

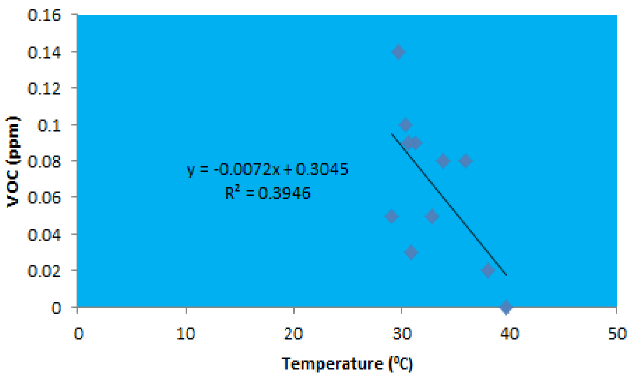

Figure 25. Correlation between VOC exposure levels and temperature for walking

4. Conclusion

CO and VOC concentrations were measured inside bus, car, BRT and while walking, and the variation of these concentrations with relative humidity, wind speed and temperature were investigated. The result and analysis revealed that temperature has negative correlation with temperature in all modes of transportation selected while CO and VOCs have positive correlations with relative humidity. It was also revealed that there is statistically meaningful difference between CO concentrations and temperature ($p<0.05$). We suggest that non-linear relationship of the meteorological parameters with these gaseous pollutants be investigated. We also suggest that further epidemiological investigation of CO and VOCs are necessary to explain relation between their concentration inside vehicles and health effects.

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