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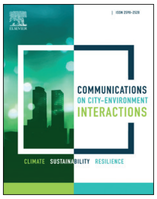

Research article

Impact of school traffic on outdoor carbon monoxide levels

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ABSTRACT

This paper aims to determine the relationship between carbon monoxide levels with vehicles, including types and motions of vehicles in a school traffic environment. Children are more vulnerable as they spend most of their time in school and their still-developing respiratory system makes them more susceptible to air pollution compared to adults. The research was carried out by direct measurement of carbon monoxide using MultiRAE Lite PGM-6208 and counting of vehicles manually using tally counter with different traffic flow scenarios, type of vehicles, school days, locations and in schools. From the findings, it is found that the measurements of carbon monoxide exposures were significantly greater in town schools compared to rural area; weekdays recorded much higher carbon dioxide levels compared to weekends; moving vehicles had stronger effects compared to idle vehicles; and light-duty vehicles (LDV) had highest among other types of vehicles. The results show a large impact of traffic management and transport mode on carbon monoxide exposures to school children in the schools.

1. Introduction

The research described in this paper forms to assess the impact of traffic management and transport mode on the exposures of outdoor carbon monoxide towards school children in a school traffic environment. There have been many studies covering school children and a variety of air pollutants but lesser literature is found when it comes to carbon monoxide specifically. The study applies a framework using the effects of vehicles flows, types, speeds, period, and location exposures, to link these with the atmospheric dispersion and spatial distribution of the pollutant concentrations, as it rarely been discussed and not well understood. Carbon monoxide (CO) was chosen for this study as over 90% of emissions in urban areas are from CO and road traffic, and other literatures demonstrated the importance of CO exposure in commuting journeys and transport mode in daily exposures, compared to other air pollutants such as NO_x, SO_x, benzene, the CO found to be significantly higher exposures [1]. Motor vehicle emissions are a common cause of anthropogenic carbon monoxide (CO). The incomplete combustion of gasoline in engine cylinders is the main source of CO from vehicles. The fuel-oxidation process, which basically means combustion, is the conversion of the fuel to lower-molecular-weight intermediate hydrocarbons, including olefins and aromatics, and their conversion to aldehydes and ketones, then to CO, and finally to CO_2. The reactions at the beginning are faster than the final conversion of CO to CO_2. Incomplete conversion of fuel carbon to CO_2 results in part from insufficient oxygen in the combustion mixture which is known as fuel-rick conditions, and insufficient time to oxidise fuel carbon fully to CO_2. CO emissions by diesel vehicles are minimal, mainly due to excess air used in the diesel combustion cycle [2].

According to [3], CO is a gas that is colourless, odourless and tasteless owing to its existence, rendering it an invisible hazard. It is the product of incomplete hydrocarbon combustion. The interaction of CO for haemoglobin molecules is about 240 times greater than that of oxygen, resulting in the production of carboxyhaemoglobin by removing the minimal oxygen [4,5]. When CO is inhaled, tissue hypoxia mainly affects areas of high blood flow and need for oxygen [6]. CO sensitivity with myoglobin is also 60 times greater than that of oxygen which causes heart failure and hypotension [7]. The toxic effect is the product of linking CO to cytochrome oxidase and inhibiting the transport chain of electrons [8]. COHb lesser than 1% in the body usually comes from endogenous production and anything as small as 1–9% in the body can cause chest pain and decreased exercise duration with ischemic heart disease [9].

In most cities, motor vehicles generally flock to schools in the morning to drop school students off and also in the afternoon to fetch them back from schools. Ambient CO trends usually show a bimodal diurnal pattern,

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with the highest concentrations typically occurring during commuting hours of the weekdays which is 7 to 9 in the morning and 4 to 6 in the evening [10]. The question arises on the kind of effects that will occur in such school traffic environments on the level of CO and also the health risk of the students who are put into such environment. Accumulation of outdoor CO may possibly be a cause to higher concentration of CO in indoor environment of schools. The spatial variability in the concentration of traffic-related pollutants in Huddersfield in terms of I/O context and their assessment results showed that there was a strong correlation between the concentrations of indoor and outdoor air pollutants [11]. Despite the enormous variety of these studies in terms of conditions and performance, most of them have been able to show a certain degree of association between indoor and outdoor air, with such a relationship obviously relying on a wide number of factors such as indoor pollutant production, outdoor pollutant concentration, air exchange rate, outdoor pollutant penetration capacity [12–14]. In many developing countries, where outdoor particle pollution is increasing, the impact of outdoor particles on the indoor environment is particularly important [15].

Various school microenvironments such as classrooms and sports field or courts are where school students spend most of their time on. Approximately, the average of school student spends about 6 to 8 h in a school. Evidences indicate that residential areas and vehicle traffics in near vicinities can be especially harmful to children due to the many air pollutants. School children within a proximity of 30 to 300 m from a main roadway showed increase in artificial stiffness [16], thickened carotid intima-media [17], reduced academic performance [18], increased absenteeism [19] an increase in clinical asthma symptoms [20] because of exposure to polluted air. Production of CO can come from natural sources and also anthropogenic ones. The human actually produces CO but at extremely small levels [21]. Despite that, man-made sources such as burning of fossil fuels, industrial activities, and motor vehicles are the main contributors of CO release in the air [22]. If one is exposed to CO, health effects can range from acute to chronic health problems such as asthma, sensory irritation and dysfunctional nervous system [23]. Hence, exposure of school children in school traffic to CO can be hazardous. Hypothetically in a school traffic environment, the congestion caused by parents' vehicle emissions and school buses emissions during certain hours of the day may cause an increase in CO which in return may cause adverse health effects to school children in the vicinity.

According to a report by the US National Academy of Sciences [24], four key differences between children and adults are identified in the origins of children vulnerability to environmental pollutants. Firstly, children breathe more air, drink more water, and eat more food than adults each day on a per-kilogram body-weight basis and therefore have proportionately greater exposures to environmental pollutants. Secondly, children's metabolic pathways are immature and therefore children are unable to rapidly detoxify and excrete many toxic pollutants. Next, children's exquisitely delicate developmental processes are easily disrupted [25]. There exist windows of vulnerability in early human development that have no counterpart in adult life. Exposure to even very low doses of toxic chemicals or other environmental hazards during these sensitive periods can increase risk of disease in childhood and across the life span [26]. Lastly, children have more future years than adults to develop diseases of long latency that may be triggered by harmful exposures in early life [27]. School students are still considered as children, thus more vulnerable than adults. The lack of knowledge on CO may cause parents or school transports to be oblivious to the possible harm of concentrated vehicle emission in a school environment where developing children spend most of their time. Also, urban areas are known to be more populated than suburban or rural areas, hence city school children might also be more susceptible. School children from schools that are situated nearby to major roads and highways are also more vulnerable to deleterious effects of these toxics due to their not fully-developed pulmonary systems [28]. Thus, there is a need to determine if emissions from school traffic can be one of the main sources of CO in a school environment. There is lack of regulation or control on school traffics at the moment. The aim of this study is to provide an insight of school traffic affecting the concentration of CO exposure.

2. Experiments

The monitoring equipment used to monitor continuous concentration of CO was MultiRAE Lite PGM-6208. A study in Nigeria used a similar type of monitor [29]. During the sampling measurement, it was carried out in an outdoor space at the school entrance. The measuring instrument was placed 1 m above ground level, a level which children usually inhale. A tripod was used as a support to keep the instrument in place. It is vital to ensure there is no disturbance of tall buildings from the sampling point to avoid blocking of air mass dispersion. Upon positioning it on ground, the instrument was warmed up by switching on 30 min before the beginning of sampling time. Any measurements taken before the sampling timeframe were omitted. This equipment is calibrated first before being used to avoid any problems in reading. The calibration process for MultiRAE Lite PGM-6208 can be done in a program mode that involves two processes which are fresh air calibration and span gas calibration. In the calibration process, the calibration adapter was installed to avoid any organic and inorganic substances from the environment to disturb the reading when the measurement is being carried out. Calibration was done to avoid any unnecessary error prior to sampling. The concentration of CO was measured in the unit of ppm (parts per million). The CO measured is an average of 10 min.

In the meantime, the number of motor vehicles in the school traffic was measured throughout the sampling period. Motor vehicles involved in this measurement were only limited to those that use fuel such as petrol and diesel which includes lorry, buses, cars and motorcycles. Vehicles that do not use fuels such as bicycles are omitted from the measurement. Both idle and passing motor vehicles were measured. Number of vehicles was calculated for a 10-minute timeframe hence, there will be 6 readings per hour and a total of 48 readings within one sampling timeframe. A tally counter was used to aid in measuring the number of motor vehicles. Types of vehicles such as motorcycle, light-duty vehicles (LDV) and heavy-duty vehicles (HDV) and, motions such as moving and idle vehicles were also measured for transport mode factors of air pollution (Fig. 1).

The measurement of CO levels at school traffics were done at 2-selected schools as case studies which are SJKCST and SKCAC and another school in rural area for comparison, SKS. Selections were done depending on the significance of the locations and the distances from the centre of the city. Two schools were chosen to represent urban areas with heavier school traffic and one controlled school is chosen to represent rural area with lesser school traffic as a comparison. The schools are required to not be nearby any major roadways, highways or industrial areas to avoid and reduce other sources of CO that may affect the data and also to prevent the occurrence of extreme data. Measurements taken at the controlled primary school helped to establish a baseline data. The baseline data is used to compare the significant differences between an urban and rural school. The whole sampling was carried out for over 2-weeks, where in each school, the drop off or pick up point were selected as the measurement point of sampling. Weekday that represents the typical school traffic flow and weekend scenario was chosen as the controlled factor to represent the absence of a typical school traffic. The sampling duration were set at a period of 8 h every day, starting from 6.00 am until 2.00 pm. The time range was chosen to represent an average school time from before the student is dropped off at school until a student ends school and is fetched either by someone personally or by school transportations. The measurement was obtained at every 10-minute average throughout the fixed 8-hour duration. Correlation analysis was performed in this study, to determine the influence factors from each variable towards CO emissions.

3. Results and discussions

3.1. Carbon monoxide concentrations in school traffic environments

Overall from the results it shows that the total average concentrations of CO at all studied schools for both weekday and weekend are recorded at 0.111 ± 0.019 ppm. During school days, the average concentration of CO

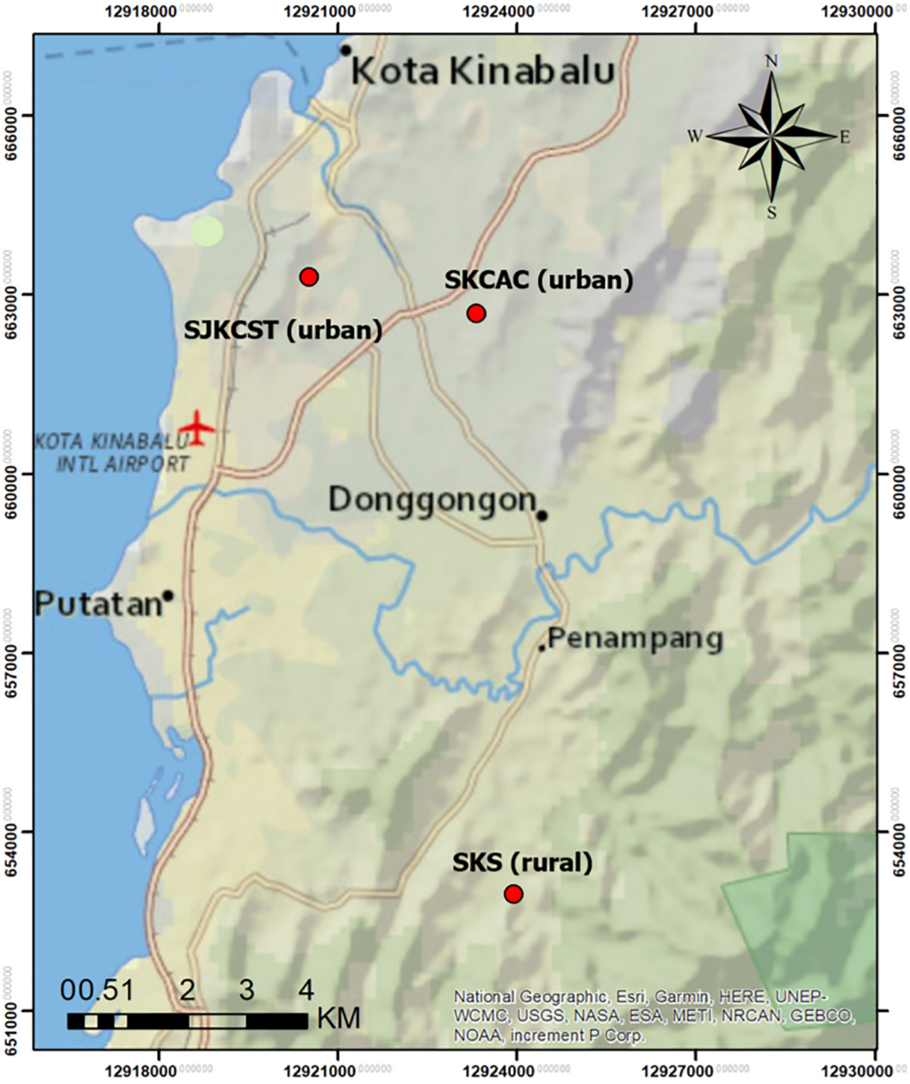

Fig. 1. Locations of selected schools for monitoring.

in SKCAC had the highest with 0.192 ± 0.034 ppm, followed by SJKCST 0.183 ± 0.020 ppm, both from urban schools, and SKS in rural with 0.133 ± 0.104 ppm. Meanwhile, during weekend, average concentration of CO in SJKCST and SKCAC both recorded at 0.015 ± 0.004 ppm and SKS at 0.1333 ± 0.110 ppm respectively. When comparing between both days, weekday had higher CO levels at total average of 0.170 ± 0.071 ppm compared to weekend at 0.053 ± 0.006 ppm. The weather on the weekday also happened to be less hot but humid with 31.14 ± 4.53 °C, 67.50 ± 13.31%, whereas it was sunnier and less humid on the weekend with temperature of 31.94 ± 5.89 °C and humidity 67.06 ± 16.82% were observed. Light-duty vehicles (LDV) had highest with total average of 9 ± 4 numbers compared with other types of vehicles, heavy duty vehicles (HDV) 3 ± 2 and followed by motorcycle 1 ± 0. Findings of the research summarized in Table 1.

3.2. Relationship of carbon monoxide levels with total number of vehicles

Bivariate correlation was undertaken to determine on how CO is being affected by the amount of vehicles. From the Table 2 it can be seen SJKCST has the most significant strong positive relationship exists on both days with r-values of 0.8444 ($p < 0.01$) on weekday and 0.8455 ($p < 0.01$) on weekend compare to the other schools. In addition, all having positive relationship which means the number of vehicles increases, the CO

Table 1
CO levels in all schools on weekday and weekend, number of vehicles and meteorological factors.

School	Motorcycle		LDV		HDV		Total vehicles	CO (ppm)	Meteorological factors	
	Idle	Moving	Idle	Moving	Idle				Temp (C°)	RH (%)
SJKCST (non-schooling)	0 ± 0	0 ± 0	4 ± 2	0 ± 0	1 ± 0	0 ± 0	4 ± 2	0.015 ± 0.004	27.46 ± 2.14	79.77 ± 9.49
SJKCST (schooling)	1 ± 0	0 ± 0	16 ± 10	9 ± 4	6 ± 4	3 ± 2	31 ± 21	0.183 ± 0.020	30.88 ± 2.72	69.94 ± 11.45
SKCAC (non-schooling)	0 ± 0	0 ± 0	1 ± 0	1 ± 0	0 ± 0	0 ± 0	2 ± 1	0.015 ± 0.004	34.82 ± 5.65	60.06 ± 14.79
SKCAC (schooling)	1 ± 0	0 ± 0	18 ± 14	2 ± 1	5 ± 3	1 ± 0	24 ± 18	0.192 ± 0.034	30.775 ± 5.50	67.77 ± 15.74
SKS (non-schooling)	2 ± 0	0 ± 0	7 ± 3	0 ± 0	4 ± 2	0 ± 0	13 ± 5	0.1333 ± 0.110	33.53 ± 6.13	61.33 ± 17.42
SKS (schooling)	2 ± 0	1 ± 0	8 ± 5	4 ± 2	4 ± 2	2 ± 1	18 ± 11	0.133 ± 0.104	31.76 ± 4.92	64.79 ± 12.08

Table 2
Bivariate correlation between concentration of CO and total vehicles.

School	Day	r-Value
SJKCST (urban)	Weekday	0.8444 ($p < 0.01$)
	Weekend	0.8455 ($p < 0.01$)
SKCAC (urban)	Weekday	0.6358 ($p < .01$)
	Weekend	0.6567 ($p < .01$)
SKS (rural)	Weekday	0.6714 ($p < .01$)
	Weekend	0.4936 ($p < .01$)

concentration will also increase. The strength shows how much of the CO actually amplifies in those studies areas [30].

3.3. Relationship of carbon monoxide levels with types of vehicles

LDV in this context refers to petrol-powered vehicles while HDV refers to diesel-powered vehicles as both emit different levels of CO. From Table 3, overall it can be seen that LDVs have the highest correlation in each schools and school days with r-values ranging from 0.4 to 0.8. The vehicles are highly correlated in SJKCST with CO emission. LDV and HDV when correlated independently with CO emissions, produced r-values of 0.81 and 0.77 respectively on both days. However, the motorcycle seems to have very weak relationship ($r = 0.1758$) on weekday and no relationship ($r = 0.0458$) on weekend. CO correlation to types of vehicles showed positive relationships with LDVs being the main contributor, although the impact varies as some show strong relationship while others show moderate levels. The possibility of HDVs and motorcycles having less number and significance correlation lesser compared to LDVs. The amount of CO produced in exhaust of a diesel engine of HDV is typically lower than that of petrol engine found in LDV [31], which also further explains why LDVs are the main contributor of CO in this study. According to [32], production of CO from gasoline engine is 28 times higher than diesel engine, showing how LDVs leads to higher CO levels than HDVs. Diesel engines produce low CO rates when consumed the fuel in excess air even at full load, at which stage the amount of fuel pumped per cycle stays around 50% stoichiometric lean [33].

3.4. Relationship of carbon monoxide levels with motion of vehicles

For motion of vehicles, moving vehicles had a stronger relationship compared to idle ones with r-values ranged from 0.5 to 0.9 both on weekday and weekend. The rest of the schools on both sample days showed moderate levels of positive relationship between concentration of CO and motion of vehicles. This shows there is almost equal chance for both moving and non-moving vehicles to affect the CO levels in the study sites. But in a general, the moving vehicles contribute better from the scatterplots of Table 4. The positive polarity shows that CO may have tendency to increase if the vehicle numbers increase, which is similar to previous correlations of vehicle numbers. The results however do not depict the other typical literatures results. Typically, vehicles that queue up at an intersection spend more time in idle driving mode, producing more pollutants per unit time, hence resulting in higher concentrations of the pollutant in the ambient air [34]. The reason for stronger moving vehicle correlation to CO is because there are higher numbers of moving vehicles.

Table 3
Bivariate correlation between CO concentration and types of vehicles.

School	Day	Vehicle type	r-Value
SJKCST (urban)	Weekday	Motorcycle	0.1758 ($p > 0.05$)
		LDV	0.8188 ($p < 0.01$)
		HDV	0.7787 ($p < 0.01$)
	Weekend	Motorcycle	0.0458 ($p > 0.05$)
		LDV	0.8100 ($p < 0.01$)
		HDV	0.7765 ($p < 0.01$)
SKCAC (urban)	Weekday	Motorcycle	0.4186 ($p < 0.01$)
		LDV	0.6642 ($p < 0.01$)
		HDV	0.4305 ($p < 0.01$)
	Weekend	Motorcycle	0.0693 ($p > 0.05$)
		LDV	0.6116 ($p < 0.01$)
		HDV	0.4669 ($p < 0.01$)
SKS (rural)	Weekday	Motorcycle	0.4211 ($p < 0.01$)
		LDV	0.6897 ($p < 0.01$)
		HDV	0.3271 ($p < 0.05$)
	Weekend	Motorcycle	0.2865 ($p < 0.05$)
		LDV	0.4290 ($p < 0.01$)
		HDV	0.2500 ($p < 0.05$)

Table 4
Bivariate correlation between motion of vehicles and CO levels.

School	Day	Motion	r-Value
SJKCST (urban)	Weekday	Moving	0.8579 ($p < 0.01$)
		Idle	0.6094 ($p < 0.01$)
	Weekend	Moving	0.8404 ($p < 0.01$)
		Idle	0.3914 ($p < 0.01$)
SKCAC (urban)	Weekday	Moving	0.6470 ($p < 0.01$)
		Idle	0.2532 ($p < 0.05$)
	Weekend	Moving	0.5642 ($p < 0.01$)
		Idle	0.5302 ($p < 0.01$)
SKS (rural)	Weekday	Moving	0.5781 ($p < 0.01$)
		Idle	0.5797 ($p < 0.01$)
	Weekend	Moving	0.5257 ($p < 0.01$)
		Idle	0.4201 ($p < 0.01$)

4. Conclusions

In conclusion, it can be seen that the traffic flow outside the schools impacts the outdoor carbon monoxide levels of the roadside. There is a strong correlation between vehicles and CO levels, r-values ranging from 0.5 to 0.8. LDVs had the highest correlation with CO among other types of vehicles, with r-values ranging from 0.4 to 0.8. As for vehicle motion, moving vehicles had a stronger relationship compared to idle ones, r-values ranging from 0.5 to 0.9. All three schools showed no significant differences despite being in urban or rural areas. However, weekday and weekend showed highly significant differences as weekday recorded much higher CO levels. As for public health and safety of the school traffic area, the highest CO concentration of 1-hour average and 8-hour average in this study are below the permissible limit set by the WHO standards. In addition, the results from this research is very important as it could can help to improve on regulations of traffic in or near school areas to control the formation of CO where school students become the main receptors of the air pollution. This study can help to further formulate interventions and policies for a healthier environment especially in the school buildings. Public awareness can also be created on the relationship between congested school traffic and health risk. Understanding CO sources and associated risk to public health can aid in developing more targeted management strategies for specific sources in order to minimise their release into the urban environment.

However, there were certain limitations in this study such as the lack of data on associated meteorological factor which are wind speed and direction. Also, the indoor CO levels were not studied, hence lack of comprehension between the indoor and outdoor relationship here. These factors might further help to understand the complex relationship of the environment studied.

CRediT authorship contribution statement

C.M. Payus: Conceptualization, Methodology, Writing - original draft, Formal analysis, Supervision. **A.T. Vasu Thevan:** Conceptualization, Methodology, Writing - original draft, Investigation, Formal analysis. **J. Sentian:** Conceptualization, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Gorai A, Tuluri F, Tchounwou P, Ambinakudige S. Influence of local meteorology and NO2 conditions on ground-level ozone concentrations in the eastern part of Texas, USA. Air Qual Atmos Health. 2015;8(1):81–96.

[2] NRC. The ongoing challenge of managing carbon monoxide pollution in Fairbanks, Alaska: interim report. Washington, DC: National Academy Press; 2002.

[3] Reumuth G, Alharbi Z, Houschyar K, Kim B, Siemers F, Fuchs P, et al. Carbon monoxide intoxication: what we know. Burns. 2019;45(3):526–30.

[4] Guo H, Morawska L, He C, Zhang Y, Ayoko G, Cao M. Characterization of particle number concentrations and PM(2.5) in a school: influence of outdoor air pollution on indoor air. Environ Sci Pollut Res. 2010;17(6):1268–78.

[5] Hitchcock G, Conlan B, Kay D, Brannigan C, Newman D. Air quality and road transport: impacts and solutions. London: RAC Foundation; 2014.

[6] Hampson N, Hampson L. Characteristics of headache associated with acute carbon monoxide poisoning. Headache. 2002;42(3):220–3.

[7] Hatami M, Naftolin F, Khatamee M. Abnormal fingernail beds following carbon monoxide poisoning: a case report and review of the literature. J Med Case Reports. 2014;8:263.

[8] Kelly F, Fussell J. Air pollution and public health: emerging hazards and improved understanding of risk. Environ Geochem Health. 2015;37(4):631–49.

[9] Bleecker M. Carbon monoxide intoxication. Occup Neurol. 2015;131:191–203.

[10] USEPA. Air quality criteria for carbon monoxide. EPA/600/P-99/001F. North Carolina: Office of Research and Development USEPA; 2000.

[11] Kingham S, Briggs D, Elliott P, Fischer P, Lebret E. Spatial variations in the concentrations of traffic related pollutants in indoor and outdoor air in Huddersfield, England. Atmos Environ. 2000;34:905–16.

[12] Kamens R, Lee C, Weiner R, Leith D. A study to characterise indoor particles in three non-smoking homes. Atmos Environ. 1991;25:939–48.

[13] Shair F, Heitner K. Theoretical model for relating indoor pollutant concentration to those outside. Environ Sci Technol. 1974;8:444.

[14] Thatcher T, Layton D. Deposition, re-suspension and penetration of particles within a residence. Atmos Environ. 1995;29:1487–97.

[15] Lee H, Kang B, Cheong J, Lee S. Relationships between indoor and outdoor or quality during the summer season in Korea. Atmos Environ. 1997;31:1689–93.

[16] Iannuzzi A, Verga M, Renis M. Air pollution and carotid arterial stiffness in children. Cardiol Young. 2010;20(2):186–90.

[17] Armijos R, Weigel M, Myers O, Li W, Racines M, Berwick M. Residential exposure to urban traffic is associated with increased carotid intima-media thickness in children. J Environ Public Health. 2015;9859:1–11.

[18] Kho F, Law P, Ibrahim S, Sentian J. Carbon monoxide levels along roadway. Int J Environ Sci Technol. 2007;4(1):27–34.

[19] Chen Q. Ventilation performance prediction for buildings: a method overview and recent applications. Build Environ. 2009;44:848–58.

[20] Wendt J, Symanski E, Stock T, Chan W, Du X. Association of short-term increase in ambient air pollution and timing of initial asthma diagnosis among Medicaid-enrolled children in a metropolitan area. Environ Res. 2014;131:50–8.

[21] Prockop L. Carbon monoxide. In: Dobbs M, editor. Clinical neurotoxicology. Philadelphia: Elsevier Inc.; 2009. p. 500–14.

[22] Ocak S, Turalioglu F. Effects of meteorology on the atmospheric concentrations of traffic-related pollutants in Erzurum, Turkey. J Int Environ Appl Sci. 2008;3(5):325–35.

[23] Tang J, Chan C, Wang X, Chan L, Sheng G, Fu J. Volatile organic compounds in a multi-storey shopping mall in Guangzhou, South China. Atmos Environ. 2005;39(38):7374–83.

[24] NAS. Pesticides in the diets of infants and children. Washington, D.C.: National Academic Press; 1993

[25] Etzel RA, Landrigan PJ. Textbook of children's environmental health. New York: Oxford University Press; 2013.

[26] WHO. Environmental health criteria 237 principles for evaluating health risks in children associated with exposure to chemicals. Geneva: World Health Organization; 2006.

[27] Carpenter DO, Bushkin-Bedient S. Exposure to chemicals and radiation during childhood and risk for cancer later in life. J Adolesc Health. 2013;52(5):21–9.

[28] Raysoni A, Stock T, Sarnat J, Chavez M, Sarnat S, Montoya T, et al. Evaluation of VOC concentrations in indoor and outdoor microenvironments at near-road schools. Environ Pollut. 2017;231:681–93.

[29] Odekanle EL, Fakinle BS, Jimoda LA, Okedere OB, Akeredolu FA, Sonibare JA. In-vehicle and pedestrian exposure to carbon monoxide and volatile organic compounds in a mega city. Urban Clim. 2017;21:173–82.

[30] Rodrigue J. The geography of transport systems. 4th ed.. New York: Oxford University Press; 2017.

[31] Dominick D, Juahir H, Latif M, Zain S, Aris A. Spatial assessment of air quality patterns in Malaysia using multivariate analysis. Atmos Environ. 2012;60:172–81.

[32] Gorai A, Tuluri F, Tchounwou P, Ambinakudige S. Influence of local meteorology and NO2 conditions on ground-level ozone concentrations in the eastern part of Texas, USA. Air Qual Atmos Health. 2015;8(1):81–96.

[33] Babu MG, Subramanian K. Alternative transportation fuels: utilisation in combustion engines. Boca Raton: CRC Press; 2013.

[34] Gokhale S, Pandian S. A semi-empirical box modeling approach for predicting the carbon monoxide concentrations at an urban traffic intersection. Atmos Environ. 2007;41(36):7940–50.