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Evaluation of hazardous airborne carbonyls in five urban roadside dwellings: a comprehensive indoor air assessment in Sri Lanka

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Abstract

Indoor hazardous airborne carbonyls were quantified in five natural-ventilated roadside dwellings in Colombo, Sri Lanka. The total concentrations of all targeted carbonyls ranged from 13.6 to 18.6 μg/m^3. Formaldehyde (C1) was the most abundant carbonyl, followed by acetaldehyde (C2) and acetone (C3K). The concentrations of C1 and C2 ranged from 3.3 to 8.5 μg/m^3 and 2.3 to 4.4 μg/m^3, respectively, which accounted for 23 to 42% and 18 to 26% respectively, to the total quantified carbonyls. The highest carbonyls levels were obtained in the dwelling located in an urban district with a mixture of industrial, commercial and residential areas. Much lower concentrations of carbonyls were measured in a light local traffic value was counted. Moderate correlations between individual combustion markers from vehicular emissions suggest the strong impacts from traffics to the indoor airs. The concentrations of C1 and C2 were compared with international indoor guidelines established by different authorities. A health assessment was conducted by estimation of inhalation cancer risk, implementing the inhalation unit risk values provided by Integrated Risk Information System (IRIS), associated with C1 and C2, which were 6.2×10^{-5} and 7.7×10^{-6}, respectively. Even though the risks did not reach the action level (1×10^{-4}), their health impact should not be overlooked. This kick-off indoor monitoring study provides valuable scientific data to the environmental science community since only limit data is available in Sri Lanka.

Keywords: Carbonyls; Indoor air quality; Carcinogenic; Dwelling; Sri Lanka.

1. Introduction

Airborne carbonyls are ubiquitous but toxic, and previous studies have shown their presences in the atmosphere are associated to the health impacts on human, such as skin allergy, eye and respiratory irritations while their levels exceed thresholds (Erdem et al., 1996; WHO, 2000, 2010). In urban areas, airborne carbonyls are mainly emitted from anthropogenic sources, including vehicular exhaust and fuel combustions in industries and power plants (Ho et al., 2006; Lui et al., 2017a; Lui et al., 2017b; USEPA, 2000), and they are also originated through photo-oxidation of hydrocarbons in atmosphere (i.e., alkenes and alkanes) (Atkinson, 2000; Carlier et al., 1986; Lui et al., 2017a).

Exposure to carbonyls in indoor environments is more critical than that in outdoors (WHO, 2010). The United States Environmental Protection Agency (USEPA) reported that people spend >90% of their time indoors (USEPA, 1989). Among those carbonyls, formaldehyde and acetaldehyde are known probable human carcinogens to human (USEPA, 2017a, b). Epidemiological studies demonstrated significant exposure-response relationship (p_{trend} < 0.001) between peak exposure to formaldehyde and nasopharyngeal cancer incidence (IARC, 2006). Acetaldehyde, the most abundant carcinogen in environmental tobacco smoke (ETS), dissolves in saliva during smoking (Salaspuro, 2009; Wang et al., 2012). Microbial or mucosal derived oxidation of acetaldehyde appears to react in the upper digestive tract as a cumulative carcinogen. Apart from carcinogenicity, accumulation of such volatile organic compounds (VOCs) could contribute to "sick building syndrome" (SBS) (Engvall et al., 2001). Residents in "sick buildings" frequently expose to VOCs that are linked with variety of human illness such as eye allergy, acute skin irritation and respiratory disease (Molhave et al., 1986; Yu and Kim, 2010). Relationship between indoor VOCs and SBS has been shown in many cross-sectional investigations on non-industrial workplaces and exposure chamber studies

(Andersson et al., 1997; Chang et al., 2015; Norback et al., 1990; Spengler et al., 2001). In indoor environment, carbonyls are released from building materials, furniture, ETS, household heating, and cooking emission (Huang et al., 2011; IARC, 2006; Kabir and Kim, 2011; Mitova et al., 2016; Salthammer et al., 2010; Svendsen et al., 2002).

Comprehensive research and well-developed programmes in air pollution control in Sri Lanka is being sought. Available air pollution studies mainly focus on cooking emissions and few of them demonstrates domestic indoor air quality (IAQ) of dwellings in Sri Lanka. List of policies and actions to improve air quality in indoor environments (CAI-Asia, 2006) were proposed by the Clean Air Action Plan 2015 of the Air Resource Management Centre (AirMAC), Ministry of Environment and Natural Resources, the Government of Sri Lanka. Sustainability contributes to the country's competitiveness because polluted environment not only pose adverse health impacts to human but also affect its productivity (Schwab, 2011). So, this is the first comprehensive indoor air quality study which provides baseline data to forthcoming monitoring and assessment in Sri Lanka. The objective of this study is to evaluate indoor levels of airborne carbonyls in urban dwellings in Sri Lanka, where were all close to roadsides. A comparison was made between formaldehyde and acetaldehyde concentrations of the dwellings and the guidelines established by different countries. The cancer risks regarding to human exposures were also accessed and are worthy of study (Bluyssen et al., 2010; Brown et al., 2010; Yu and Crump, 2010). This study aims to provide valuable scientific data to the environmental science community.

2. Experimental Section

2.1 Site Selection

In accordance with the Census of Population and Housing 2012, Colombo is a western province in Sri Lanka. It has a population of 2.32 millions (11.4% of the total population in the country) with a density of 3,438 persons per km^2. Five roadside dwellings, which were situated in an overpopulated urban areas and suburbs in Colombo, were selected in this study including Kalubowila, Pelawatte, Pitakotte, Battaramulla, and Rajagiriya. The sampling sites were chosen on the basis of (a) districts, (b) zone classes, (c) land use, (d) distance to the main road and traffic condition, and (e) without recent renovation. A brief description of each dwelling is shown as follow (further general information about the sampling sites is shown in Table 1). Figure 1 shows the locations of five dwellings. Four of these dwellings were near the heavily trafficked trunks with traffic volumes more than 500 vehicles per hour. H1 was situated in a mixed area of residential, industrial and commercial buildings which was 5 m from a 2-lane carriageway, whereas H2 was situated in an urban residential area and it was close to a 4-lane trunk with only a 1-meter width pedestrian pathway splitting between the sampling site and trunk. H4 and H5 were both located in urban commercial areas, near a 2-lane carriageway. A dwelling, H3, was situated in a sub-urban/rural residential area next to a small local street with fewer than 152 vehicles per hour traffic volume.

2.2 Field sampling

Sampling campaign was held from March 13th to 27th April, 2010. The time selection was due to minimal impact from poor meteorological conditions (i.e., lower rainfall recorded in spring, compared with that in summer). Carbonyl samples were collected for 12 hours (from 07:00 to 19:00 local time) in living rooms of five dwellings. Three sampling events were collected in each dwelling and one sample was collected in each event. Two extra sampling events were conducted in H2. The samplers and monitors were situated at least 1 m away from the walls and 1.5 m above ground. No particular indoor pollution source was found in the

indoors. The distances between the nearest road and respective sampling sites were recorded. During the sampling events, the airs inside the living rooms were ventilated naturally with open windows and front door. No air-conditioning was operated in all rooms. The living room sizes ranged from 150 to 200 m^2. No decoration had been done and no new furnishing had been installed at all five sampled dwellings within five years. Any indoor pollution activity (e.g., cooking or other indoor combustions) were prohibited inside the dwellings at least 24 hours prior to and during the sampling event. For outdoor, no any commercial restaurant and other obvious pollution sources except traffic emissions were located near the roadside dwellings (<200 m). In addition, traffic counts were conducted to investigate the relationship between traffic volume and indoor carbonyl levels. Vehicle fleets and traffic volumes were determined by manual counting at the roadsides, at a ten-minute per hour basis. Vehicles were classified into six major categories: (1) bus, (2) dual purpose van, (3) lorry, (4) motor bike, (5) three-wheeler, and (6) private car. A log of occupants' daily activities was remarked at each site.

Carbonyl sampler were used to collect airborne carbonyls by drawing ambient air through an acidified 2,4-di-nitrophenylbydrazine impregnated cartridge (Sep-Pak DNPH-silica, Waters Corporation, Milford, MA, USA). Sampling pump was operated at 0.7 L/min and calibrated by a DryCal® gas flow meter (Bios International Corp., Butler, NJ, USA) prior to and after sample collections. No breakthrough was reported at this sampling flow rate and time (Dai et al., 2012; Waters Corporation, 2007). Ozone interference was eliminated by connecting an ozone scrubber (Sep-Pak, Waters Corporation, Milford, MA, USA) in front of the DNPH cartridge. The sampled cartridges were capped and packed, and stored in an ice-box and transported to the laboratory for chemical analysis. The temperature, relative humidity (RH) and carbon dioxide (CO_2) concentration were recorded by Q-Trak™ indoor air quality monitor (model 8550; TSI, Inc., Shoreview, MN, USA). Air exchange rate of each dwelling was

145 determined by the decay rate of CO_2 level in accordance with the American Standard Test
146 Method [ASTM, E741-00(2006)e1] (ASTM International, 2006). Linear portion of decay
147 period was extracted and respective air exchange rate was measured.

148 **2.3 Chemical Analysis**

149 A total of 16 carbonyls (14 monocarbonyls and 2 dicarbonyls) were quantified (as listed
150 with abbreviations on Table 2). Similar to our previous studies, this study will not report the
151 amount and abundances of two unsaturated carbonyls, acrolein and crotonaldehyde because
152 excess derivatization reagent can react with unsaturated carbonyl DNP-hydrazones and
153 produce adducts which gives inaccurate quantification result (Dai et al., 2012; Ho et al., 2011).
154 Further information of the DNPH-coated cartridge extraction, instrumental analysis, and
155 quality control and quality assurance (QA/QC) can be referred to Lui et al. (2017b), Dai et al.
156 (2012), and Ho et al. (2014a, 2014b, 2016). A four-point calibration for each target carbonyl
157 over a concentration range of 0.015–3.0 mg/mL from the certified standards (Supelco,
158 Bellefonte, PA) was established, and the correlation coefficients (r^2) for linear regressions of
159 the calibration curves were at least 0.999. The minimum detection limit (MDL) was done by
160 analyzing at least seven replicates of a standard solution containing the analytes at a
161 concentration of 0.015 μg/mL. The MDL can be estimated by equation (1):

162 $$\mathrm{MDL} = t_{(n-1,\ 1-\alpha=99\%)} \times S \qquad (1)$$

163 where $t_{(n-1,\ 1-\alpha=99\%)}$ is the student's t-distribution value at n−1 degrees of freedom, and *S* is the
164 standard derivation of the replicates (Meier and Zünd, 2005; Skoog et al., 1998). MDLs of the
165 targeted carbonyls varied between 0.002 and 0.010 μg/mL, which refer to 0.034 – 0.045 ppbv
166 with 0.72 m^3 sample volume.

167 **2.4 Cancer risk calculation**

168 Cancer risk due to chronic inhalation of carbonyls was assessed. Cancer risk estimation is
169 denoted by the likelihood of cancer incidence from a continuous lifetime exposure to a specific
170 carbonyl. The Inhalation Unit Risk (IUR) for formaldehyde and acetaldehyde are 1.3×10^{-5}
171 and 2.2×10^{-6}, respectively. The lifetime cancer risk (R) is determined by following equation
172 (3):

173 $$R = IUR \times \text{concentration exposure} \qquad (2)$$

174 **3. Results and Discussion**

175 **3.1 Traffic count and physical conditions**

176 Table 3 lists the traffic volumes and physical parameters measured at the five sampled
177 roadside dwellings. The highest traffic volume of 1,582 vehicle/hour was recorded in a 4-lane
178 main trunk outside H2, followed by H5 (1,356 vehicle/hour) and H1 (1,287 vehicle/hour). The
179 lowest traffic volume of 152 vehicle/hour, only accounting for 10% of the average value of
180 the other sites, was counted in a local road close to H3. The air exchange rates of living rooms
181 ranged from 3.6 and 4.6 h^{-1}. The average temperature and RH ranged from 30.3 to 32.1°C and
182 71 to 80%, respectively.

183 **3.2 Carbonyl concentrations**

184 Figure 2 shows the average concentrations of the targeted carbonyls quantified in
185 dwellings (acronyms for carbonyls are shown in Table 2). Formaldehyde (C1), 4.9 ± 1.6 μg/m^3
186 on average, was the most abundant carbonyl, which accounted for 32 ± 6.5% of the total
187 quantified carbonyls on mass base. Acetaldehyde (C2) and acetone (C3K) were the following
188 two abundant carbonyls with average concentrations of 3.5 ± 0.7 μg/m^3 (23 ± 2.7%) and 2.3

± 1.2 μg/m^3 (14 ± 6.9%), respectively. Other carbonyls such as isovaleraldehyde (isoC5) and methylglyoxal (mgly) had lower contributions of 7.1% and 4.8%, respectively.

The highest total carbonyl concentration was measured at H1 (18.6 μg/m^3), where also had the highest average concentrations of C1 (7.6 μg/m^3) and C2 (4.0 μg/m^3), accounting for 41% and 21%, respectively, of the total quantified value. The next highest C1 concentration was found in H5 (34% of the total quantified carbonyls), whereas H4 had the next highest C2 concentration (24% of the total quantified carbonyls). Most of the lowest abundances of carbonyls were seen in the H3, where had an average total quantified carbonyl concentration of 13.7 μg/m^3, reflecting the significance of traffic emissions influenced to the indoor air quality of other urban roadside dwellings. C1 and C2 are known incomplete combustion products emitted from vehicular engines (Baez et al., 1995; Grosjean, 1982; Viskari et al., 2000). In comparison, similar sum of C1 and C2 concentrations (i.e., C1+C2) were found in all dwellings, except H1, with averages ranged from 6.9 to 7.5 μg/m^3.

3.3 Impact of outdoor sources on indoor airs

High air exchange rates could be resulted from a large number of windows featured in the sampled dwellings. During the sampling periods, as usual as general residential practice in Sri Lanka, the windows and room doors were opened. Therefore, indoor air quality in the dwelling could be significantly affected by the infiltration of the outdoor air. The total carbonyl concentration at H1, where located in an urban residential-commercial-industrial mixed district, was significantly higher than that measured in the H3. This demonstrates that the emissions from various anthropogenic pollution sources could greatly contribute to the carbonyls at the sampling location (Chan et al., 2011; Ho et al., 2002; Wang et al., 2010a). It has been documented that C1 and C2 levels were at least 10% higher at the microenvironment near roadsides than the areas away from traffic emission (Ho et al., 2012; Morknoy et al.,

213 2011). If H1 was removed from the comparison, the carbonyl levels have strong association
214 with the traffic volume near the sites. However, H1 obtained the highest level of carbonyls.
215 This can be attributed to the fact that the background carbonyls from other local anthropogenic
216 activities around the district were also contributed to the elevation of pollutants in the indoor
217 airs. Other factors such as the individual air exchange rate and differences in meteorological
218 parameters could affect the absolute concentrations.

219 Table 4 lists the C1/C2 ratios in this study and compared with other relevant researches. It
220 was known that C1/C2 ratios vary from 1 to 2 in urban districts and around 10 for sub-urban
221 and rural districts (Wang et al., 2010a). The mean C1/C2 ratio of the five sampled dwellings
222 was 1.4, suggesting that strong impacts of anthropogenic emission on the sites (Wang et al.,
223 2010a). In general, our C1/C2 ratios were within the ranges measured in urban areas recorded
224 in other studies. The highest C1/C2 ratio of 1.9 was observed in H1, whereas H3 had the lowest
225 C1/C2 ratio of 0.9. The low ratio at H3 can be ascribed to the real situation that no any biogenic
226 source, other than vehicular emission, was found around the site. Vehicular emission from the
227 local road was the sole anthropogenic pollution source contributing to the carbonyls emission
228 among H2, H3, H4 and H5. Industrial sources in the urban areas might also have various
229 amounts of C1 and C2 emissions which were reflected in the samples collected in H1.

230 **3.4 Correlations between carbonyls**

231 The correlations between C1 and C2, C1 and benzaldehyde (Benz), C1 and m-
232 tolualdehyde (mtol), C1 and mgly are shown in Figure 3. Those are the important components
233 in the exhausts of diesel/gasoline-fueled vehicles (Ban-Weiss et al., 2008; Ho et al., 2006).
234 Weak correlation between C1 and C2 ($R = 0.4$, $p < 0.01$) was observed in this study. However,
235 moderate correlation between C1 and mtol ($R = 0.69$, $p < 0.01$) and strong correlations between
236 C1 and Benz, ($R = 0.88$, $p < 0.01$), and C1 and mgly ($R = 0.83$, $p < 0.01$) were obtained among

all of the sampled dwellings. The results evidenced that the carbonyl levels in the indoor airs of the dwellings were attributed to the traffic emissions.

3.5 Health assessment

Table 5 shows the comparison of C1 and C2 concentrations with the indoor air quality guidelines established by World Health Organization (WHO), Office of Environmental Health Hazard Assessment (OEHHA), Japan National Institute of Health Sciences (JNIHS) and China Indoor Air Quality Center (CIAQC). Inhalation is a main exposure pathway for VOCs intakes for human apart from ingestion and dermal absorption. The C1 indoor exposure guideline established by both WHO, JNIHS and CIAQC is 100 $\mu g/m^3$, while a much stricter chronic C1 reference exposure level was established by the OEHHA (9 $\mu g/m^3$). Both C1 and C2 concentrations measured in the sampled dwellings were well below the tolerable levels.

Figure 4 lists the chronic cancer risks calculated for C1 and C2 in this study. C1, C2 and their potential health risks were determined because of their high abundances in micro-environments and their carcinogenicity categorized by USEPA (1998). Housewives or maids who often stay in the dwellings were the targeted population for the assessment. Inhalation exposure is linked with the degree of exposure. The lifetime cancer risk for C1, C2 were estimated as shown in Figure 4. Risk below 1×10^{-6} is usually considered as acceptable risk to a hazard. Risk above 1×10^{-4} is considered as action level, and interventions should be implemented to protect individual who is under particular exposure (Lee et al., 2006). The lifetime cancer risks associated with C1 and C2 among the five sampled dwellings ranged from 4.3×10^{-5} to 9.9×10^{-5} and 6.5×10^{-6} to 8.7×10^{-6}, respectively. Even though the estimated cancer risks for C1 and C2 did not reach the action level, their health impact should not be overlooked. C1 contributes most to lifetime cancer risks, which was eight folds to the lifetime cancer risk raised by C2. Especially for H1, the risk level for C1 exposure was

merely below the action level. Table 6 compares the cancer risk on C1 and C2 exposures calculated in other studies. Our inhalation cancer risks associated with both C1 and C2 were lower than those in Hangzhou in China, Xalapa in Mexico and Shimizu in Japan, where those areas were known as heavily polluted cities in the world (Baez et al., 2003; Ohura et al., 2006; Weng et al., 2009).

4. Conclusions

This is the first comprehensive indoor air quality study conducted in Sri Lanka. C1, C2, and C3K were the three most abundant carbonyls quantified in the indoor airs in the roadside dwellings. Their sum of concentrations accounted for 68% of the total quantified carbonyls. The correlation analysis of individual markers proves that traffic emission was the main pollution source contributed to the carbonyl levels in the indoor airs of the dwellings. The C1/C2 ratio was within the range of those reported in other metropolitan cities, suggesting that local anthropogenic activities play an important role on the carbonyls production in Colombo. The indoor C1 and C2 concentrations were all below the tolerated levels established by those international health authorities. Even though the estimated lifetime cancer risks associated with C1 and C2 were also lower than the risk level, the possible health impact should not be overlooked. This study not only evaluated the air pollutant levels, and acted as a kick-off action on the indoor air monitoring and health assessment in Sri Lanka.

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284 Relations Division, Ministry of Environment, Sri Lanka for providing the technical supports,
285 chemical analytical facilities and the logistical arrangements of the study.

LIST OF FIGURE CAPTIONS

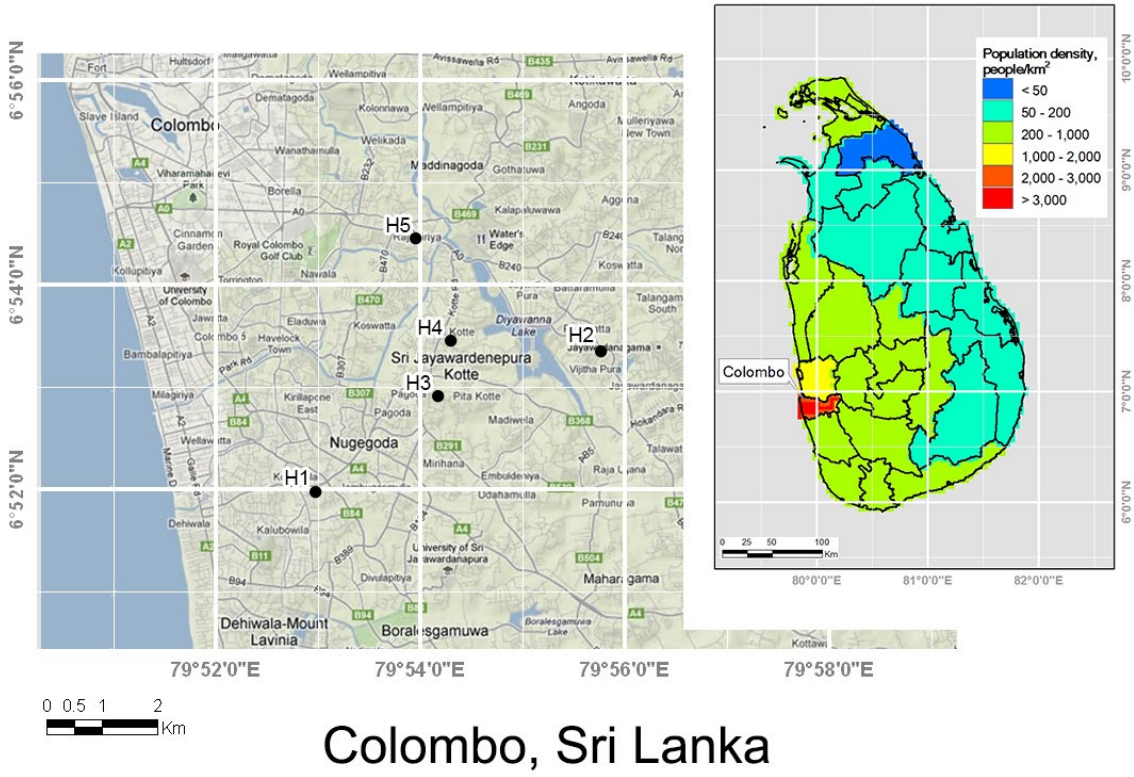
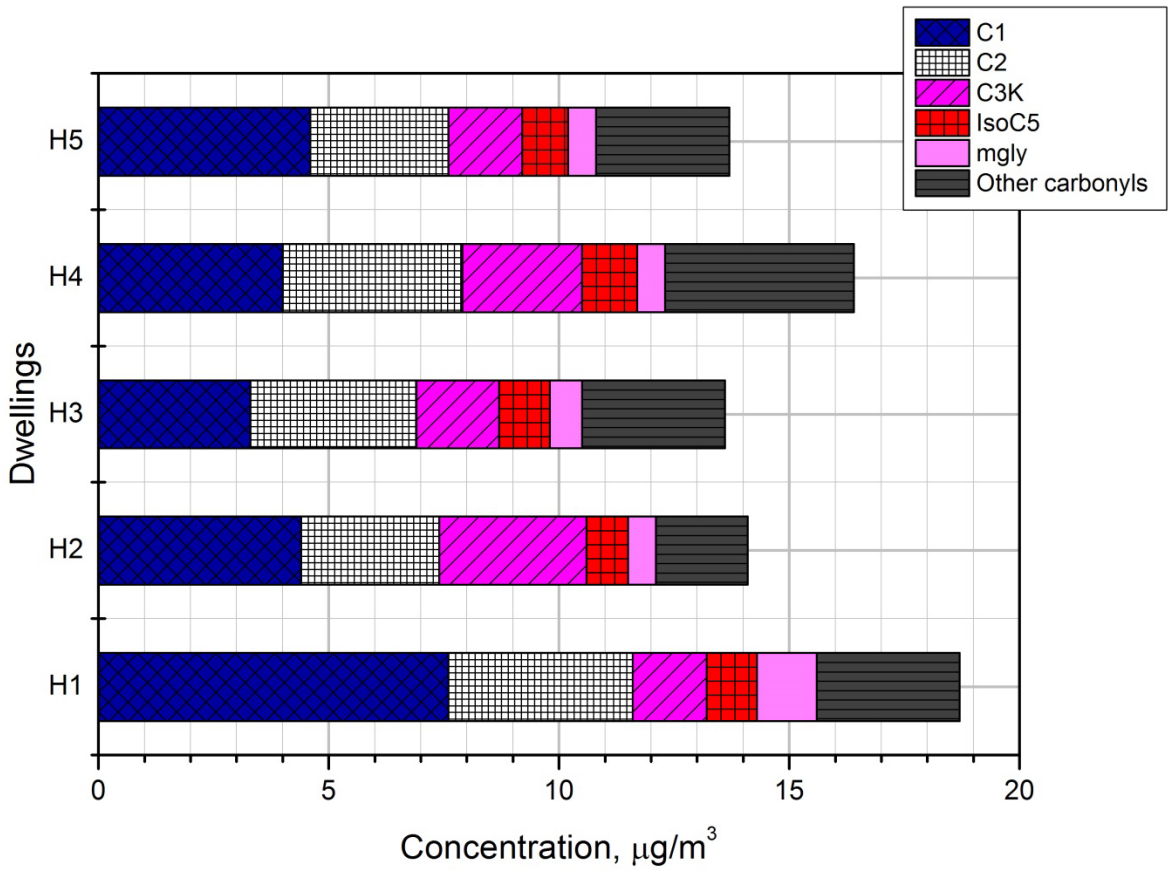


Figure 1 A map shown the districts and sampled dwellings in Colombo, Sri Lanka. Measurement sites are shown in the figure. H1, H2, H3, H4 and H5 refer to Kalubowila, Pelawatte, Pitakotte, Battaramulla and Rajagiriya, respectively. The general information of each site are provided in **Table 1**.

299

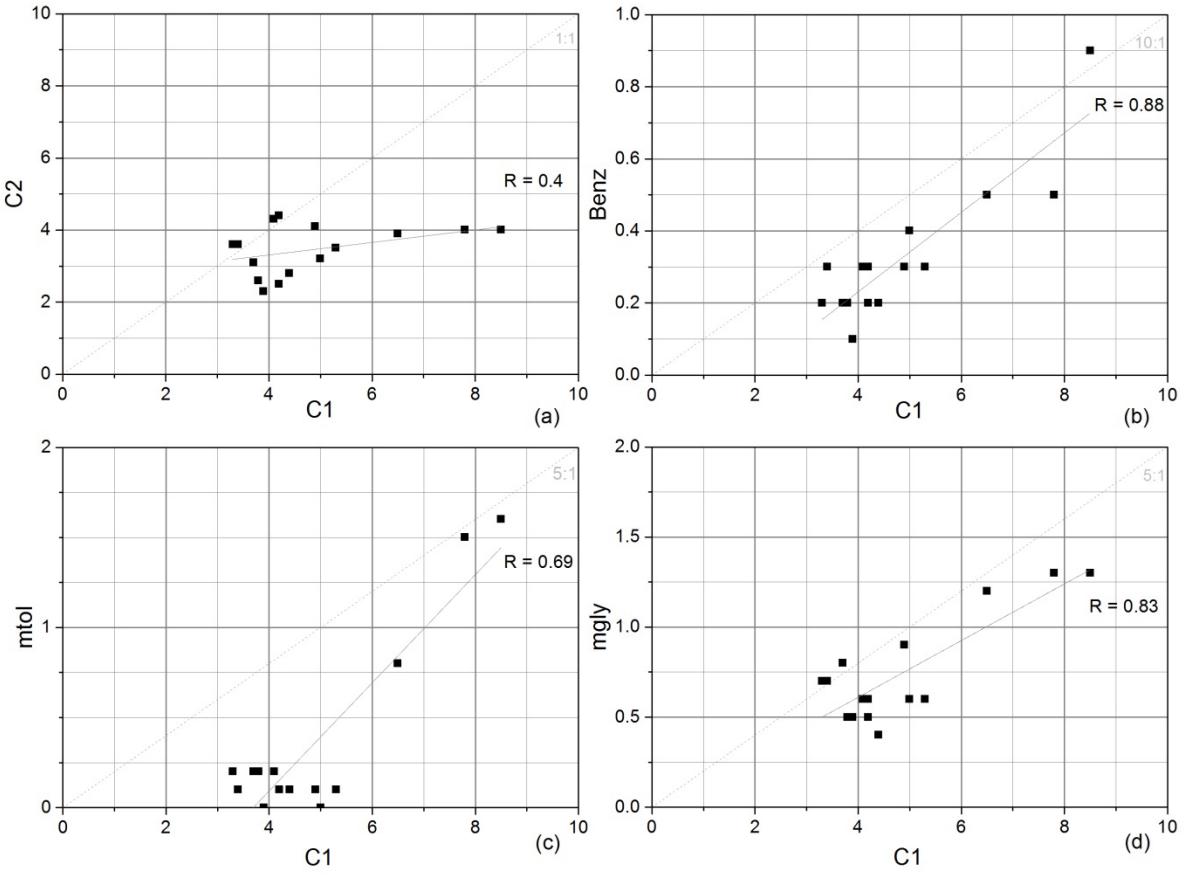


300

301 **Figure 2** The 12-hr average carbonyl concentrations (μg/m^3) measured in the sampled

302 dwellings.

303

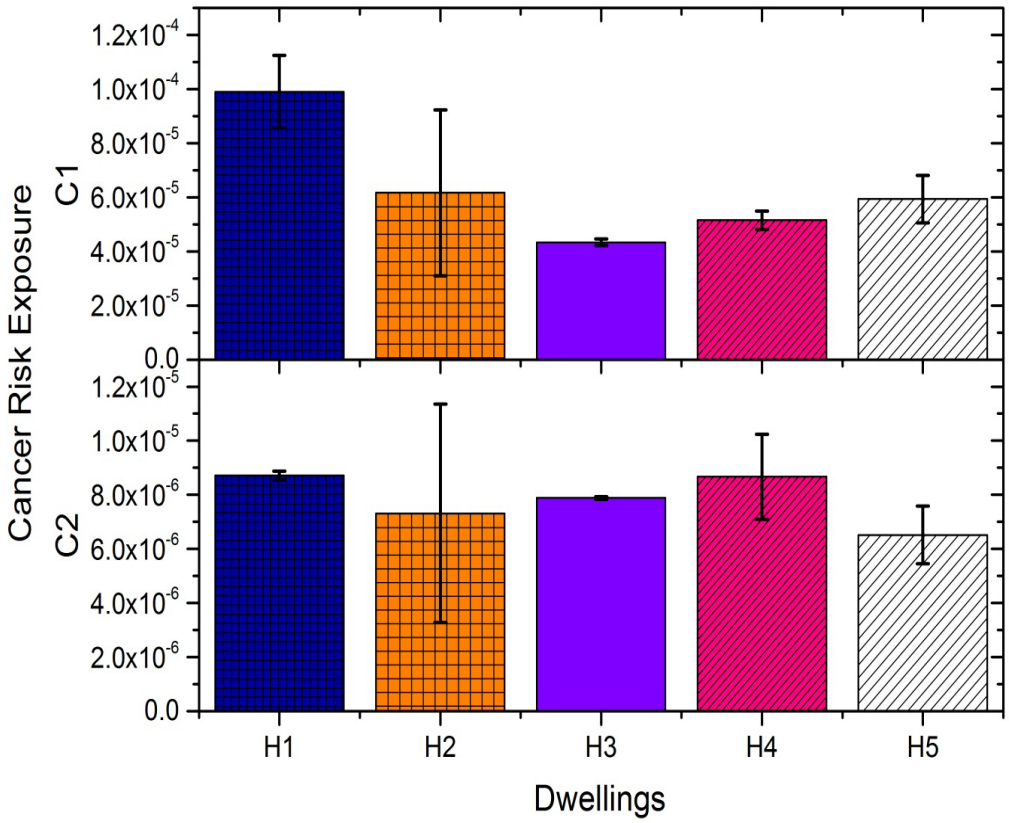


304

305 **Figure 3** Scatter plots for concentrations (μg/m^3) of (a) C1 against C2; (b) C1 against Benz;

306 (c) C1 against mtol; and (d) C1 against mgly.

307



308

309 **Figure 4** Chronic cancer risks associated with C1 and C2 estimated in the sampled

310 dwellings.

311 **LIST OF TABLE CAPTIONS**

Table 1. General information of sampling sites in Colombo, Sri Lanka.

Site/district	Class	Area	Distance from main road & traffic condition
H1 (Kalubowila)	Urban	Mix[a]	5 meters from the 2-lane carriageway
H2 (Pelawatte)	Urban	Residential	1 meter from the 4-lane trunk
H3 (Pitakotte)	Suburban/rural	Residential	1 meter from the single lane local road
H4 (Battaramulla)	Urban	Commercial	5 meters from the 2-lane carriageway, close to two main trunk
H5 (Rajagiriya)	Urban	Commercial	15 meters from the 2-lane carriageway

[a] Mix: Area consists of residential, commercial and industrial

Table 2. Sixteen targeted carbonyls and their abbreviation in this study.

Pollutants	Acronyms
Formaldehyde	C1
Acetaldehyde	C2
Acetone	C3K
Propionaldehyde	nC3
Methyl-ethyl-ketone	MEK
i-/n-Butyraldehyde	isonC4
Benzaldehyde	Benz
Isovaleraldehyde	isoC5
n-Valeraldehyde	nC5
o-Tolualdehyde	otol
m-Tolualdehyde	mtol
p-Tolualdehyde	ptol
n-Hexaldehyde	C6
2,5-Dimethylbenzaldehyde	2,5-DB
Glyoxal	gly
Methylglyoxal	mgly

Table 3. Physical parameters obtained in the roadside dwellings and estimated hourly traffic volume (derived by 10-minute average).

Dwellings	H1		H2		H3		H4		H5	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
General Information										
Temperature (°C)	32.1	1.8	30.3	1.5	31.9	1.1	30.6	1.3	31.2	1.3
Relative Humidity (%)	71.4	7.9	76.8	4.6	74.8	5.2	79.4	4.9	79.7	2.2
Air Exchange Rate (h^{-1})	3.8		4.6		4.6		4.2		3.6	
Areas	250		170		150		200		200	
Traffic Count										
Bus	98	20	35	12	1	2	30	14	269	41
Dual purpose van	162	42	254	66	14	8	85	32	162	46
Lorry	70	25	141	47	10	9	50	19	109	40
Motor bike	248	57	277	106	61	25	152	48	277	106
Three-wheeler	347	65	241	59	53	22	121	30	267	70
Private car	362	84	635	115	13	9	245	45	273	64
Sum	1,287		1,582		152		683		1,356	

Table 4. Comparison of formaldehyde/acetaldehyde (C1/C2) ratio with other studies.

Location	C1/C2	References
Colombo, Sri Lanka	1.4	This study
Kalubowila H1	1.9	
Pelawatte H2	1.5	
Pitakotte H3	0.9	
Battaramulla H4	1.0	
Rajagiriya H5	1.5	
California, U.S.A.		(Bradman et al., 2017)
Indoor	2.2	
Outdoor	1	
Sao Paulo, Brazil	2.1	Nogueira et al. (2014)
Rio de Janeiro, Brazil	1.4	Correa et al. (2010)
Kaohsiung City, Taiwan	1.3	Wang et al. (2010b)
Gyung Gi, South Korea	1.0	Pal et al. (2008)
Strasbourg, France	1.9	Marchand et al. (2006)
Santiago, Chile	0.9	Rubio et al. (2006)
Beirut, Lebanon	1.6	Moussa et al. (2006)
Beijing, China	1.1	Pang and Mu (2006)
New Mexico	2.4	Villanueva-Fierro et al. (2004)
New York, USA	2.3	Sax et al. (2004)
Athens, Greece	1.0	Bakeas et al. (2003)
Xalapa, Mexico	1.3	Baez et al. (2003)
Hong Kong, China	2.2	Ho et al. (2002)
Rio de Janeiro, Brazil	1.0	Grosjean et al. (2002)
Milan, Italy	1.4	Andreini et al. (2000)
Rome, Italy	1.3	Possanzini et al. (1996)
Schauinsland, Germany	1.0	Slemr et al. (1996)
New Jersey, USA	3.2	Zhang et al. (1994)

Table 5. Comparison of indoor air quality guideline of C1 and C2 established by OEHHA, WHO, JNIHS and CIAQC.

Cabonyls	Standards			
μg/m^3	WHO[a]	OEHHA[b]	JNIHS[c]	CIAQC[d]
C1	100	9	100	100
C2	-	140	48	

a: World Health Organization: Guideline for indoor air quality – selected pollutants (WHO, 2010); b: Office of Environmental Health Hazard Assessment, CA, US: Chronic reference exposure level (REL) (OEHHA, 2016) ; c: Japanese National Institute of Health Sciences (JNIHS, 1997); d: China Indoor Air Quality Center: Indoor air quality standard GB/T18883-2002 (CIAQC, 2003)

Table 6. Comparison of cancer risks associated with C1 and C2 obtained in other indoor studies.

City, Country	Cancer risk		Indoor type	Estimated exposure period (years)	References
	C1 ($\times 10^{-5}$)	C2 ($\times 10^{-6}$)			
Colombo, Sri Lanka	4.3 – 9.9	6.5 – 8.7	Dwellings	70	This study
Fortaleza, Brazil	0.3 – 3.6	2.3 – 13	Hospitals	40	Sousa et al. (2011)
Hong Kong, China	1.0 – 1.6	3.1	Kitchens	70	Huang et al. (2011)
Hangzhou, China[a]	26 – 130	21 – 71	Dwellings	70	Weng et al. (2010)
Xalapa, Mexico[b]	49 – 61	43 – 59	Dwellings	78	Baez et al. (2003)
Xalapa, Mexico	34 – 130	42 – 100	Office	78	Baez et al. (2003)
Fortaleza, Brazil[c]	0.6 – 2.3	7 – 23	Office	40	Cavalcante et al. (2006)
Shimizu, Japan[a]	14.2	11	Dwellings	70	Ohura et al. (2006)

[a] Geometric means of summer and winter periods
[b] Arithmetic mean values
[c] Values estimated in Pici Campus with a 40 years exposure

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