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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.

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, 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,

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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 3438 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). Fig. 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 h (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 h 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

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.