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Concentrations, sources and human health risk of inhalation exposure to air toxics in Edmonton, Canada

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HIGHLIGHTS

- Health risk and sources of ambient air toxics assessed in Edmonton for 2009–2013.
- Carcinogenic risks of air toxics were below acceptable and/or tolerable risks.
- Traffic and background/secondary organic aerosol contributed >60% to total HAPs.
- Findings are useful for developing risk management and controlling air toxics.

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ABSTRACT

With concern about levels of air pollutants in recent years in the Capital Region of Alberta, an investigation of ambient concentrations, sources and potential human health risk of hazardous air pollutants (HAPs) or air toxics was undertaken in the City of Edmonton over a 5-year period (2009–2013). Mean concentrations of individual HAPs in ambient air including volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs) and trace metals ranged from 0.04 to 1.73 μg/m^3, 0.01–0.54 ng/m^3, and 0.05–3.58 ng/m^3, respectively. Concentrations of benzene, naphthalene, benzo(*a*)pyrene (BaP), arsenic, manganese and nickel were far below respective annual Alberta Ambient Air Quality Objectives. Carcinogenic and non-carcinogenic risk of air toxics were also compared with risk levels recommended by regulatory agencies. Positive matrix factorization identified six air toxics sources with traffic as the dominant contributor to total HAPs (4.33 μg/m^3, 42%), followed by background/secondary organic aerosol (SOA) (1.92 μg/m^3, 25%), fossil fuel combustion (0.92 μg/m^3, 11%). On high particulate air pollution event days, local traffic was identified as the major contributor to total HAPs compared to background/SOA and fossil fuel combustion. Carcinogenic risk values of traffic, background/SOA and metals industry emissions were above the USEPA acceptable level (1×10^{-6}), but below a tolerable risk (1×10^{-4}) and Alberta benchmark (1×10^{-5}). These findings offer useful preliminary information about current ambient air toxics levels, dominant sources and their potential risk to public health; and this information can support policy makers in the development of appropriate control strategies if required.

1. Introduction

Exposure to hazardous air pollutants (HAPs), commonly known as air toxics is of concern due to potential carcinogenic and other adverse health effects including respiratory, neurological, reproductive and developmental effects (Delfino, 2002; Windham et al., 2006; USEPA, 2012). Under the United States 1990 Clean Air Act Amendments, 187 air toxics have been identified that warrant specific attention and long-term monitoring, and 30 HAPs have been defined as urban air toxics which pose the greatest potential threat to public health in urban areas (USEPA, 2016a,b). In Canada several of these 187 HAPs are treated as 'toxic substances' by Health Canada under Canadian Environmental Protection Act (CEPA) 1999.

Characterization of ambient air toxics is beneficial for understanding sources and human health risks of HAPs based on inhalation exposure. HAPs may consist of a variety of organic and inorganic species including volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs) and metals. They can be emitted from a wide range of natural (e.g., forest fires) and

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anthropogenic sources including traffic, fossil fuel industries, residential and commercial heating, evaporation processes, paints and solvent industries (Wu et al., 2007; Logue et al., 2009). Strum and Scheffe (2015) recently analyzed ambient air observations of 27 HAPs across the United States in order to characterize national concentrations and risks of urban air toxics. In Canada Galarneau et al. (2016) investigated ambient concentrations of 63 air toxics under the National Air Pollution Surveillance (NAPS) program. However, to the best of our knowledge limited source and risk apportionment studies (e.g., Logue et al., 2009; Wu et al., 2007; Kavouras et al., 2015) have been carried out worldwide so far to investigate sources of measured ambient HAPs out of the lists of 187 USEPA air toxics and their associated risk to public health in urban areas.

Edmonton (area 684 km^2, population of 877,926 in 2014) is the second largest urban area and the centre of the Capital Region of Alberta and is located on the North Saskatchewan River, about 300 km north of Calgary and about 400 km east of the foothills of the Canadian Rockies. Edmonton has a relatively humid continental climate with wide fluctuations in seasonal temperatures. In general, cold winter and mild summer seasons last from November 15 to March 15 and May 15 to September 15, respectively. Average prevailing wind directions are west-northwesterly and early morning surface inversions are common throughout the whole year in Alberta with deeper and stronger inversions observed in November through January (Myrick et al., 1994; AESRD, 2014). The city is surrounded by numerous fossil fuel industries (8 km east: Strathcona petroleum refineries; ~30 km northeast: Alberta's industrial heartland in Fort Saskatchewan-several chemical and petrochemical industries, manufacturing industries e.g., steel mill; ~70 km west: coal-fired generating plants) and agricultural farming lands (Myrick et al., 1994; Schulz and Kindzierski, 2001; AESRD, 2014) (Supplemental Information-SI, Fig. S1). National Pollutant Release Inventory (NPRI) (Environment Canada, 2016a) annual releases of VOCs, PAHs, and some trace metals (e.g., As, Ni) to the air from major industrial facilities/operations in and surrounding Edmonton and in Alberta (Fig. S2, Tables S1, S2) for 2009–2013 are shown in the SI. In previous studies traffic, industrial activities and biomass burning were found as dominant emission sources of ambient and outdoor VOCs (McCarthy et al., 2013; Bari et al., 2015a) and trace metals in submicron particles (PM_1) (Bari et al., 2015b) in Edmonton and the surrounding region.

A recent media release stated that Alberta was on track to have worst air quality in Canada (National Post, 2015a). In addition, a Canadian physicians group claimed that Edmonton experienced higher levels of harmful air pollutants compared to Toronto and blamed coal-fired power generating plants for Edmonton's poor air quality (National Post, 2015b). This raises questions about current levels of air pollutants of public health concerns in Edmonton and the surrounding region. A study was therefore carried out to characterize selected air toxics of public health concerns for the most recent years in Edmonton. The objectives of this study were to better understand ambient levels of air toxics, determine their potential local and long-range sources in Edmonton and evaluate their risk to public health.

2. Methodology

2.1. Ambient sampling and chemical analysis

The study was undertaken using available HAPs data collected from air monitoring stations in Edmonton. Under Environment Canada's NAPS program, Alberta Environment and Parks (AEP) routinely monitors criteria air pollutants including HAPs in Edmonton air monitoring stations (Fig. S1). The study was carried out using publicly available HAPs data for a 5-year period (2009–2013) accessed via Environment Canada (2016b). Ambient 24 h data for 33 hazardous volatile organic compounds (VOCs) were taken from Edmonton central station. VOC samples were collected at a frequency of once every 6 days using 6-L evacuated Summa canisters (Scientific Instrumental Specialists, Inc.) and analyzed by gas chromatograph-mass spectrometer (GC-MS) at Environment Canada's lab in Ottawa. Details of VOCs sampling and analysis methods are described elsewhere (Wang et al., 2005; Galarneau et al., 2016). Data for 9 PAHs including 7 carcinogenic ones were taken from Edmonton McIntyre station (collected 1-in-6 day frequency) for the study period except in 2012 (collected 1-in-6 day frequency at Edmonton east station). Data for 9 hazardous trace metals in $PM_{2.5}$ were obtained from Edmonton McIntyre station. Ambient 24 h integrated $PM_{2.5}$ samples were collected gravimetrically using Partisol 2300 sequential speciation sampler (Thermo Fisher Scientific, USA) on a 1-in-3 day and trace metals were analyzed by inductively-coupled plasma mass spectrometry (ICP-MS). Further details of the analytical methods and quality assurance/quality control (QA/QC) procedures are described elsewhere (Celo et al., 2010; Dabek-Zlotorzynska et al., 2011; McCarthy et al., 2013). Winter and summer wind roses at McIntyre station were generated for the 5-year study period (2009–2013) (Fig. S3) based on historical hourly meteorological observations via the AEP airdata warehouse (AEP, 2016a). Twenty-four hour concentration data for secondary pollutants (SO_4^{2-}, NO_3^-, NH_4^+), organic carbon (OC), elemental carbon (EC) and other organic (e.g., levoglucosan, arabitol) and elemental (e.g., Ba, Cu, V, Zn) markers were also accessed for the study period for Edmonton McIntyre station via Environment Canada (2016b).

2.2. Source apportionment method

To identify and apportion possible emission sources of ambient HAPs in Edmonton, the United States Environmental Protection Agency (USEPA)'s multivariate receptor model positive matrix factorization (EPA PMF5.0) (USEPA, 2014a) was used. Details of the model description, data treatment procedure, uncertainty or error estimation methods are presented in the SI. The input file included a 5-year dataset (2009–2013) consisting of 205 daily (24 h) samples (excluding one sample due to outlier), where all measured HAPs data (VOCs, PAHs, trace metals) were available on selected days. Out of 51 measured HAPs, 37 species including 19 VOCs, 9 PAHs and 9 trace metals were selected for PMF analysis based on their higher frequency of detection (specifically, those HAPs with at least 50% of the data above the method detection limit (MDL)) and using selected HAPs as source-specific markers (refer to Table S3). Multiple linear regression (MLR) analysis was conducted to regress total measured HAPs against PMF-derived factor contributions in order to determine the relative contribution of each of the identified sources to total measured HAPs. Different statistical approaches were applied to verify the PMF-resolved source assignments. Data for criteria air pollutants and meteorological parameters were used to investigate their relationship with identified sources by calculating Spearman's rank correlation coefficient for each source. To better identify and characterize potential local emission sources, a conditional bivariate probability function (CBPF) (Uria-telelaetxe and Carslaw, 2014) was calculated using PMF-derived factor contributions by coupling conditional probability function (CPF) with bivariate polar plots in order to show hidden contributions from different source types through their wind speed dependence. The impact of potential long-range sources was also investigated using the concentration-weighted trajectory (CWT)