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Full Length Article

Eight-year (2007–2014) trends in ambient fine particulate matter ($PM_{2.5}$) and its chemical components in the Capital Region of Alberta, Canada

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ABSTRACT

Currently there have been questions about ambient fine particulate matter ($PM_{2.5}$) levels in the Capital Region of Alberta, Canada. An investigation of temporal trends in $PM_{2.5}$ and its chemical components was undertaken in the City of Edmonton within the Capital Region over an 8-year period (2007–2014). A non-parametric trend detection method was adopted to characterize trends in ambient concentrations. No statistically significant change was observed for ambient $PM_{2.5}$ concentrations during 2007–2014, while significant decreasing trends were found for organic carbon, elemental carbon, oxalate, barium, lead and cadmium. A statistically significant increasing trend was observed for sodium chloride indicating an increase of de-icing salt contribution for winter road maintenance in recent years. Concentrations of potassium ion and zinc exhibited strong and significant seasonal variability with higher concentrations in winter than in summer likely reflecting wood smoke origins more than other potential sources in Edmonton and the surrounding region. No statistically significant changes were observed for all other chemical components examined. Notwithstanding robust population growth that has occurred in Edmonton, these findings reveal that particulate air quality and corresponding trace elements in Edmonton's air has been unchanged or improved over the investigated period (2007–2014). Longer-term air quality monitoring at least over several decades is needed to establish whether trends reported here are actually occurring.

1. Introduction

Exposure to ambient fine particulate matter i.e., $PM_{2.5}$ (with aerodynamic diameter <2.5 μm) is of increasing public concern over the past decades. A number of epidemiological studies suggest an association between long-term and short-term exposure to $PM_{2.5}$ and increased morbidity, mortality and emergency hospital admissions for cardiovascular, cerebrovascular (stoke) and ischemic heart disease as well as diabetes and neurological disorders (Pope et al., 2014; Zanobetti et al., 2014; Burnett et al., 2014; Weichenthal et al., 2014; Lippmann, 2014). Apart of its deleterious effects on public health, studies also indicate that particulate matter affects visibility and climate change (Cheung et al., 2005; Forster et al., 2007).

Characterization of ambient $PM_{2.5}$ is complex and an understanding of their sources, sinks, temporal and spatial variation is needed. At present, there is not enough evidence at the population level to identify differences in the effects of particles with different chemical compositions or emanating from various sources. Nevertheless, there is a body of evidence that chemical composition of particles may be valuable and appropriate information for evaluating PM health risk in addition to particle number and mass concentrations (Forsberg et al., 2005; Cassee et al., 2013; Dominici et al., 2015; Peters et al., 2015). From a toxicological point of view, some trace elements and their compounds (e.g., arsenic, cadmium, cobalt, chromium, mercury, manganese, nickel, lead, antimony, selenium) fall under the list of toxic substances (arsenic, lead, mercury, cadmium, nickel) as defined by Health Canada under the Canadian Environmental Protection Act (CEPA, 1999) and are also considered hazardous under the United States Environmental Protection Agency Clean Air Act (U.S. EPA, 2009). Some studies indicate that crustal-derived elements (e.g., silicon, aluminum, calcium, iron) are predominant in coarse particles ($PM_{10-2.5}$), and appear to be less potentially toxic than combustion-derived trace elements (e.g., lead, arsenic chromium, nickel, zinc, cadmium and selenium), which are more abundant in fine particle fractions (i.e., $PM_{2.5}$) suggesting that smaller sizes, composition and sources of particles are important factors in toxicity (U.S. EPA, 2009; Dominici et al., 2014).

Canadian Ambient Air Quality Standards (CAAQS) for $PM_{2.5}$ were developed in 2012 through a collaborative process involving federal, provincial and territorial governments and stakeholders and the Canadian Council of Ministers of the Environment (CCME, 2012). Under the Air Quality Management System (AQMS), Canadian provinces and territories will need to determine if a given air zone achieves the CAAQS. Previously, a 24 h Canada-Wide Standard (CWS) for $PM_{2.5}$ of 30 μg/m^3

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was established and has been used to assess and manage urban air quality issues since 2000 (CCME, 2000). The new CAAQS for $PM_{2.5}$ was developed in 2012 and it will replace and is more stringent than the CWS. The new 24 h and annual average CAAQS for $PM_{2.5}$ for the year 2015 are 28 μg/m^3 and 10 μg/m^3; while for the year 2020 they are 27 μg/m^3 and 8.8 μg/m^3, respectively (CCME, 2012).

Recently there has been increasing public concern about the status of particulate air pollution in the Capital Region (Edmonton and immediate surrounding area) of Alberta. A recent investigation of air quality event days represented by elevated hourly concentrations of ambient $PM_{2.5}$ was undertaken in the Capital Region (AESRD, 2014). Results indicated that elevated hourly $PM_{2.5}$ concentrations near roadways did not co-vary with traffic volumes at roadway locations near air monitoring stations and nitrogen dioxide concentrations on 'high-hourly concentration' event days. AESRD (2014) suggested that air quality monitoring stations are not impacted by primary fine particulate matter from vehicle traffic. It was also suggested that fine particulate matter on event days may be the result of formation of secondary fine particles from regional precursor sources that may include, but are not limited to, vehicle emissions. The study concluded that the fine particulate matter issue in the Capital Region is complex.

Another recent study was conducted in six Alberta air zones to assess potential compliance with the new 2015 CAAQS for $PM_{2.5}$ for the time period of 2011–2013 (Alberta Environment and Parks, 2015). It was reported that in the North Saskatchewan air zone which includes the Capital Region, the Edmonton East air quality monitoring station had $PM_{2.5}$ metric values (24 h average: 38.2 μg/m^3, annual average: 11.0 μg/m^3) above the new CAAQS in 2013. Recent media releases reported by the Canadian Association of Physicians for the Environment (CAPE) also claimed that Edmonton had higher levels of harmful air pollutant compared to a big city like Toronto and $PM_{2.5}$ exceeded CWS of 30 μg/m^3 on several winter days in 2010 through 2012 (National Post, 2015). This raises questions about the current state of particulate matter air quality in the City of Edmonton. It was therefore of particular interest to further investigate the state of air quality in the region to understand how poor or good it is for fine particulate matter in Edmonton.

Evaluating ambient air quality monitoring data is important for characterizing and understanding the state of air quality and whether it is changing. In this study, we made an in-depth investigation of trends, monthly and annual concentration profiles of $PM_{2.5}$ and its chemical components using available data for last 8 years (2007–2014). The objective of this investigation was to establish, whether concentrations of $PM_{2.5}$ and its chemical composition have changed over the last 8 years.

2. Methodology

2.1. Study area

Edmonton is the capital and second largest city in Alberta with a population within its municipal boundaries of 877,926 in 2014 (Municipal Census, 2015). The Capital Region of Alberta (Supplementary information, Fig. S1) includes the Edmonton Census Metropolitan Area, Lamont County, and the Elk Island National Park. It covers an area of 11,993 km^2, accounts for 1.9% of Alberta's land mass and 31.8% of Alberta's population (AESRD, 2014). The Capital Region has a relatively humid continental climate with wide variations in seasonal temperatures. Daily average temperatures range from −10.4 °C in January to 17.7 °C in July. Prevailing wind directions are west-northwesterly and early morning surface inversions are frequent throughout the whole year (Myrick et al., 1994). AESRD (2014) used upper air sounding data from weather balloons released twice daily at the Environment Canada Stony Plain weather observation station located 25 km west of Edmonton to calculate the occurrence of inversion conditions by month for 2006–2011 for the Capital Region. The monthly percent frequency of inversion conditions for this period is illustrated in Fig. S2 and it shows that inversion conditions occurred most frequently in November through January. The major emission sources of $PM_{2.5}$ and precursor gases in the Capital Region include petroleum refining, light-manufacturing, and fugitive emissions from holding tanks or petroleum terminals as well as transportation, space heating (e.g., wood burning fireplaces), coal- and gas-fired electrical power generating units located 60 km to the west, wildfires smoke and biogenic emissions and other non-specific industrial sources (Myrick et al., 1994; Schulz and Kindzierski, 2001; AESRD, 2014). Over the 10-year period 2004–2014 the city added 177,270 residents to its population (City of Edmonton, 2015) and 19,800 more registered vehicles each year (average) using its roadways (Alberta Transportation, 2008, 2012, 2014).

The study was conducted in Edmonton using historical data measured at Environment Canada's National Air Pollution Surveillance (NAPS) $PM_{2.5}$ chemical speciation monitoring station at Edmonton McIntyre (53° 29′ 9.8″ N, 113° 27′ 52.5″ W). The location of Edmonton McIntyre station and three other air monitoring stations (Edmonton south, central and east) is shown in Fig. 1. The station is located to the south of Edmonton and close to highway 14 (Whitemud Drive). A wind rose plot was generated (Fig. S3) to show a 8-year (2007–2014) average prevailing wind direction at the monitoring station using historical hourly meteorological data publically available from the Clean Air Strategic Alliance (CASA, 2015) data warehouse. The wind rose plot indicates a general tendency for winds to be from southerly and west-northwesterly directions at Edmonton McIntyre station. Prevailing winds blew from the south direction 40% of the time and from the west-northwest 23% of the time over the 8-year period at Edmonton McIntyre.

2.2. Sampling and analysis

As part of Environment Canada's NAPS program, Alberta Environment and Parks (AEP) routinely monitors criteria air pollutants including $PM_{2.5}$ in Edmonton air monitoring stations. Up to 2009, hourly concentrations of $PM_{2.5}$ had been measured at all Edmonton stations using Tapered Element Oscillating Microbalances (TEOM). Since May 2009 the Environment Canada NAPS program adopted the United States Environment Protection Agency's Federal Equivalent Method (FEM) i.e., TEOM coupled with Filter Dynamics Measurement Systems (TEOM-FDMS) in order to ensure comparability of continuous monitors to a reference method and to capture semi-volatile components of the $PM_{2.5}$ mass (Government of Canada, 2013; Alberta Environment, 2013). Edmonton McIntyre station has been used for quality assurance for $PM_{2.5}$ monitoring methods, where TEOM-FDMS has been deployed since November 2006. Data for hourly $PM_{2.5}$ concentrations from TEOM-FDMS at Edmonton McIntrye station was accessed for the 2007–2014 period via the CASA data warehouse (CASA, 2015).

Data was also accessed for ambient 24 h integrated $PM_{2.5}$ sampling that has been performed at Edmonton McIntyre station at a frequency of once every 3 days from 2007 as part of the NAPS $PM_{2.5}$ speciation program. Samples are collected using co-located Thermo Scientific samplers (Partisol-Plus 2025D sequential dichotomous particle sampler, Partisol 2300 sequential speciation sampler) and analyzed by the Analysis and Air Quality Section (AAQS) of Environment Canada in Ottawa. Data for $PM_{2.5}$ components including organic carbon (OC), elemental carbon (EC), major water soluble ions as well as heavy and trace metals were accessed for the 2007–2014 period from NAPS data products made available to the public by Environment Canada (2015a). Details of the data analytical methods and quality control are presented elsewhere (Celo et al., 2010; Dabek-Zlotorzynska et al., 2011).

2.3. Data analysis

Data for trend analysis of hourly $PM_{2.5}$ concentrations from continuous monitoring at Edmonton McIntrye station was obtained in temporal order of year, month, day, and hour. A cut-off criterion of 80%