Atmospheric Pollution Research xxx (xxxx) xxx–xxx

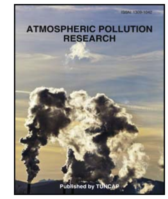
HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Atmospheric Pollution Research

journal homepage: www.elsevier.com/locate/apr



Characterization of air quality and sources of fine particulate matter ($PM_{2.5}$) in the City of Calgary, Canada

Md. Aynul Bari*, Warren B. Kindzierski

School of Public Health, University of Alberta, 3-57 South Academic Building, 11405-87 Avenue, Edmonton, Alberta, T6G 1C9 Canada

ARTICLE INFO

Keywords:
$PM_{2.5}$
Calgary
Positive matrix factorization
Backward trajectory
Secondary aerosol

ABSTRACT

With concern about fine particulate matter ($PM_{2.5}$) pollution in urban areas and levels approaching a new Canadian Ambient Air Quality Standards (CAAQS), an exploratory study of air quality characteristics and potential sources affecting $PM_{2.5}$ levels was undertaken in the City of Calgary, Alberta. The study was performed for the economic recession period 2014 to 2016 using hourly concentrations of criteria air pollutants at two monitoring stations (Calgary central and Calgary northwest). The overall mean and median $PM_{2.5}$ concentrations were similar at both Calgary central (arithmetic mean: 7.7 μg/m^3, median: 6.0 μg/m^3) and Calgary northwest (arithmetic mean: 7.5 μg/m^3, median: 6.0 μg/m^3). Three-year averages of annual average daily 24 h $PM_{2.5}$ concentrations at both stations were below the 2015 annual CAAQS of 10 μg/m^3 during the study period 2014–2016. A multivariate receptor model positive matrix factorization (PMF) revealed five sources, where secondary aerosol was identified as the largest source of $PM_{2.5}$ contributing 54% at Calgary central and 42% at Calgary northwest. Other sources included combustion (18%, 39%), traffic (18%, 12%), an O_3-rich source (8%, 4%), and a mixed urban source (2%, 3%) at Calgary central and Calgary northwest, respectively. Variations in annual contributions of secondary aerosol, combustion and traffic were observed at Calgary downtown for 2014–2016. At Calgary northwest no variation was found for annual traffic contributions. These findings offer preliminary information about the contributions of different potential sources to $PM_{2.5}$ in Calgary; and this information can support policy makers in developing appropriate air quality management initiatives for $PM_{2.5}$ pollution if needed.

1. Introduction

There has been growing awareness and public health concerns about the state of air quality in urban areas. Urban air pollution is generally caused by a wide variety of emission sources including traffic, industry, commercial/residential fuel combustion and is comprised of a complex mixture of gaseous and particulate air contaminants such as nitrogen dioxide (NO_2), sulfur dioxide (SO_2), fine particulate matter ($PM_{2.5}$), and ground-level ozone (O_3). Epidemiological studies suggest potential associations between short- and long-term exposure to criteria air pollutants and increased morbidity, mortality and hospital admissions for cardiovascular and pulmonary diseases, stroke, as well as decreased life expectancy (Burnett et al., 1999, 2004; Ruidavets et al., 2005; Pope et al., 2014; Weichenthal et al., 2014; Zanobetti et al., 2014). High concentrations of these pollutants can also contribute to acid deposition, photochemical smog and reduced atmospheric visibility (Cooper and Alley, 2002; Cheung et al., 2005). This has led the Canadian Council of Ministers of the Environment (CCME) to the establishment of health-based air quality standards i.e., Canadian Ambient Air Quality Standards (CAAQS) as a driver for air quality management across the country with an objective to guide work towards better understanding and, where necessary, controlling air emissions in populated urban areas. The new CAAQS for $PM_{2.5}$ for the year 2015 (annual: 10 μg/m^3, 24 h: 28 μg/m^3) and 2020 (annual: 8.8 μg/m^3, 24 h: 27 μg/m^3) (CCME, 2012) replaced the former 24 h Canada-Wide Standard (CWS) of 30 μg/m^3 established in 2000 (CCME, 2000).

The City of Calgary is the largest urban area and most populous city (area 825 km^2, population 1,246,337, Municipal census, 2017) in the oil and natural gas-rich province of Alberta and third-largest municipality in Canada (Statistics Canada, 2016). It is located about 300 km south of Alberta's capital Edmonton in a valley at the foothills approximately 80 km east of the front ranges of the Canadian Rockies. The city anchors the south end of the Calgary-Edmonton Corridor, which is home to 2.7 million people. Alberta has well-established conventional oil and gas extraction, refining and upgrading activities in addition to unconventional oil sands development in the northeast area of the

Peer review under responsibility of Turkish National Committee for Air Pollution Research and Control.
* Corresponding author.
E-mail address: mdaynul@ualberta.ca (Md. A. Bari).

https://doi.org/10.1016/j.apr.2017.11.014
Received 25 September 2017; Received in revised form 27 November 2017; Accepted 28 November 2017

province. Calgary is located within the southern edge of oil and gas extraction activities (Supplemental Information-SI, Fig. S1a). Because of its diversified economy including oil and gas, film and television industries, transportation and logistics, technology, manufacturing, retail, and tourism sectors, Calgary plays a key role in supporting economic growth of Alberta and Canada.

Evaluation of long-term air monitoring data and characterization of ambient $PM_{2.5}$ can aid in improving the understanding of the state of air quality and sources of particle pollution in urban areas. In our recent study (Bari and Kindzierski, 2016a), we observed more than 40 (80) exceedances of the 24 h $PM_{2.5}$ CWS of 30 μg/m^3 (1 h Alberta Ambient Air Quality Guideline of 80 μg/m^3), respectively over a 17-year period (1998–2014) in Calgary. In addition, the highest 3-year average (2010–2012) of 24 h concentrations was recorded in downtown Calgary among Canadian urban areas. In another study conducted for the time period 2010–2012 in six Alberta airsheds including South Saskatchewan Air Zone where Calgary is located (Fig. S1b), the Government of Alberta (Alberta Environment and Parks-AEP, 2015) reported that air monitoring stations at Calgary central and Calgary northwest had annual $PM_{2.5}$ metric values of 7.5 μg/m^3 (in 2013) and 8.5 μg/m^3 (3-year average). The study assigned Calgary to an orange management level for $PM_{2.5}$ based on four-color coded air quality management thresholds for 2015 (Table S1), suggesting that $PM_{2.5}$ concentrations were approaching the new CAAQS and proactive planning and/or action may be needed to prevent exceedances. It was therefore of interest to undertake an exploratory study to evaluate $PM_{2.5}$ levels and to identify different emission sources that affect $PM_{2.5}$ levels in Calgary.

In general, 24 h $PM_{2.5}$ chemical speciation data has been widely used in multivariate receptor models to identify and distinguish different emission sources in urban areas. Due to cost, however many monitoring organizations do not have the capabilities and financial resources to routinely monitor for $PM_{2.5}$ chemical species. Environment and Climate Change Canada (ECCC) only performs $PM_{2.5}$ speciation monitoring in selected major urban centers of Canada (e.g., Edmonton, Toronto, Vancouver, Montreal) (ECCC, 2017a; Bari and Kindzierski, 2016b). In Alberta local airshed monitoring organizations work collaboratively with Alberta Environment and Parks to operate air quality monitoring networks and monitoring stations in cities, small towns and rural areas and measure real-time concentrations of gaseous pollutants and $PM_{2.5}$. Due to lack of $PM_{2.5}$ speciation data, numerous studies have been carried out worldwide to characterize sources of ambient fine particulate matter, nanoparticles, particle size distribution using real-time concentrations of gaseous pollutants data (e.g., Yue et al., 2008; Thimmaiah et al., 2009; Hellebust et al., 2010; Sun et al., 2014; Khan et al., 2015; Al-Dabbous and Kumar, 2015; Sowlat et al., 2016). Using only real-time gaseous pollutant data in receptor models may provide a limited number of source factors and may not be able to identify some specific sources (e.g., road dust, secondary organic aerosol, biogenic). In addition, this approach may also not be able to distinguish different industry-related sources (e.g., metallurgy, refinery, cement kiln) that can be important sources in urban areas of Alberta. However, the approach can offer useful preliminary information highlighting potential major emission source types that affect air quality at a receptor location in urban areas. In our recent studies (Bari and Kindzierski, 2017a,b), we used the positive matrix factorization (PMF) model to investigate $PM_{2.5}$ sources in the third largest urban area (Red Deer) and a small rural community (Hinton) in Alberta using gaseous pollutant data. In this exploratory study, we characterized air quality and investigated emission sources that affect $PM_{2.5}$ levels in the largest city of Alberta – Calgary using real-time continuous air monitoring data.

2. Methodology

2.1. Study areas

As part of ECCC's National Air Pollution Surveillance (NAPS) initiatives, the Calgary Region Airshed Zone Society (CRAZ, http://www.craz.ca) has been responsible for regional air quality monitoring and providing results to Alberta Environment and Parks. The CRAZ airshed boundaries include the cities of Calgary and Airdrie, the Municipal Districts of Rocky View, Bighorn and Foothills, Willow Creek, Vulcan and Wheatland Counties, the Improvement Districts of Kananaskis and Banff, and the Town of Canmore (Fig. S1c). The topographical map of the City of Calgary and immediate surrounding area is shown in Fig. S2a. Average daily (24 h) weekday traffic volume for the City of Calgary in 2016 is shown in Fig. S2b.

Calgary has a humid continental climate with wide fluctuations in temperatures throughout the seasons e.g., long cold winters and warm summers and no dry season. Seasonal average daily temperatures typically range from −6.8 °C in December to 16.5 °C in July and the average annual precipitation is in terms of rain 33 cm and snow 129 cm (ECCC, 2017b). Due to close proximity to the Rocky Mountains, Calgary's air quality can be influenced by warm and dry Chinook winds that blow over the mountains during winter months (Hicks and Mathews, 1979). Winter temperatures are also affected by the wind chill factor, with a high average wind speed of 14.2 km/h in Calgary, one of the highest in Canadian cities. Early morning ground-based temperature inversions are common throughout the whole year in Alberta with deeper and stronger inversions observed during winter months (Hicks et al., 1977; Myrick et al., 1994), thus limiting the dispersion of air pollutants and potentially increasing pollutants levels in winter.

According to Environment Canada 2006 and CRAZ 2008 emissions inventories, major point sources of air pollutant emissions in the CRAZ region are several upstream oil and gas facilities, cement and other industrial activities (e.g., construction). There are also non-point sources e.g., transportation, residential and commercial heating and open area sources including agricultural operations and field/stock burning as well as solvent and biogenic emissions (Novus Environmental, 2013). In the City of Calgary, contributions to total emissions were noteworthy for transportation (carbon monoxide, CO: 89% of total emissions, oxides of nitrogen, NO_X: 79%, $PM_{2.5}$: 9%), construction related fugitive emissions ($PM_{2.5}$: 62%), cement industry (sulfur dioxide, SO_2: 40%) and commercial and residential heating (SO_2: 28%, $PM_{2.5}$: 9%) (Table S2). National Pollutant Release Inventory (NPRI) (ECCC, 2017c) reported annual releases of SO_2, NO_X, $PM_{2.5}$, and volatile organic compounds (VOCs) to the air from major industrial facilities within 50 km of downtown Calgary are shown in Table S3. Notable energy development activities are upstream oil and gas developments located within and surrounding the City of Calgary. For example, several oil and gas industries such as Inter Pipeline Extraction Ltd.-Cochrane Extraction Plant, Taqa North Ltd.-East Crossfield Gas Plant, Enmax Generation Portfolio Inc.-Shepard Energy Centre and Direct Energy Marketing Ltd.-Wildcat Hills Gas Plant are located from 35 km northwest, 39 km north, 16 km southeast and 44 km northwest from Calgary central, respectively (Table S3). Over the 10-year period 2004–2014 the city added 261,700 residents to its population (City of Calgary, 2015), and 26,170 more registered vehicles each year (average) using its roadways (Alberta Transportation, 2015).

The study was performed using historical air quality data collected from two air monitoring stations – one in downtown Calgary i.e., Calgary central (51.0472° N, 114.0731° W, elevation 1051 m) and one in a residential area in Calgary northwest (51.0792° N, 114.1419° W, elevation 1106 m) (Fig. 1). The local emission sources at Calgary central are traffic and commercial operations, while at Calgary northwest potential sources include residential heating, traffic and small-scale industries (e.g., cement industry located within 10 km northwest from the Calgary northwest station, Table S3). Other industries are located to the east and southeast of Calgary within 5–10 km from Calgary downtown. Over the last 10 years, Calgary downtown station was moved ~100 m west to Calgary central 2 (51.0459°N, 114.0747° W) on April 2008 and 4.9 km southeast to Calgary-central Inglewood