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The contribution of road traffic to particulate matter and metals in air pollution in the vicinity of an urban road

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ABSTRACT

A detailed investigation was conducted to study the sources of particulate matter in the vicinity of an urban road in Žilina. To determine the amount of particulate matter (PM_{10}, $PM_{2.5}$ and PM_1) present in the ambient air, a reference gravimetric method was used. The main objective of this contribution was to identify the sources of these particles by means of statistical methods, specifically principal component analysis (PCA), factor analysis (FA), and absolute principal component scores (APCS), as well as using the presence of 17 metals in the particulate matter (Na, Mg, Al, Ca, V, Cr, Fe, Mn, Ni, Cu, Zn, As, Mo, Sb, Cd, Ba, Pb). To identify the metals in the particulate matter samples and to determine their abundances, spectroscopic methods were used, specifically inductively coupled plasma mass spectrometry (ICP-MS). Each of these metals may come from a specific source, such as the burning of fossil fuels in fossil fuel power plants; local heating of households; the burning of liquefied fossil fuels in the combustion engines of vehicles; the burning of coal and wood; non-combustion related emissions resulting from vehicular traffic; resuspension of traffic-related dust; and industry. Diesel vehicles and non-combustion emissions from road traffic have been identified as two key sources of the particulate matter. The results reveal that non-combustion emissions, which are associated with the elements Na, Fe, Mn, Ni, Zn, Mo, Sb, Cd, and Pb, are the major contributors, followed by combustion emissions from diesel vehicles, which are associated with the elements Mg, Ca, and Ba.

1. Introduction

Emissions of particulate matter from different sources create a very complex mixture in the air in both qualitative and quantitative terms. Their chemical compositions (in terms of chemical elements and compounds) is the result of the distribution of all the sources in space and time and the magnitudes and characteristics of the pollutants on the one hand, and meteorological and climatic conditions on the other (Tecer, 2013; Tiwari et al., 2014; Jandacka and Durcanska, 2014; Licbinsky et al., 2010).

Heavy metals are among the most basic groups of contaminants that are monitored in various parts of the environment (Balachandran et al., 2000; Chen et al., 2010). The subjects of monitoring, pursuant to the general law (Act of the National Council No. 137/2010), are the following elements: As, Cd, Hg, Pb and Ni. These are generally considered as the most harmful to people and animals. These heavy metals may prove to be highly toxic to living organisms, and at the same time they are

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very persistent in the outdoor environment (that is, they do not decompose over time through environmental processes), while at the same time, they bio-accumulate in the food chain (EEA, 2013). Some of the other elements may also be dangerous; these elements can be found in soils, where they are necessary in small amounts. However, when accumulated in large quantities, they may have a toxic impact. The following elements may have these characteristics: Cr, Co, Sn, Sb, Cu, Ni, Ag, Au, Zn, Mo, V, Mn, Fe and others (Durza, 2003).

These elements (metals) are bound up with fine particles of aerosols. Heavy metals enter the environment via natural and anthropogenic processes (Weinbruch and Ebert, 2004; McCullum and Kindzierski, 2001; Gatari et al., 2006; Vojtesek et al., 2009; Thorpe and Harrison, 2008; Pant and Harrison, 2013; Sanderson et al., 2014; Kukutschova et al., 2011). Natural sources include in situ weathering processes and atmospheric deposition of metals, oceanic processes and volcanic eruptions. Anthropogenic sources include the burning of fossil fuels in order to generate electricity, raw materials excavation and ore processing, industrial processes, agricultural activities, local combustion and the continuously increasing usage of motor vehicles. In particular, vehicular traffic is the sole contributor to the presence of particulate matter in the vicinity of urban roads in medium-size cities (Chen et al., 2010).

This contribution characterizes the issue of air pollution involving particulate matter in the urban environment while it attempts to identify its main sources. As the main source of pollution, we shall therefore consider vehicular traffic, which produces combustion-related emissions, non-combustion related emissions, and road dust. The profiles of metals in particulate matter was used to identify the sources in an urban area. The links between the different chemical elements (metals) were identified by using multivariate statistical methods, specifically PCA, FA, and APCS, in conjunction with Multivariate Regression Analysis (MRA) (Kachigan, 1991; Manly, 2004; Meloun and Militky, 2006; Meloun et al., 2012; Spencer, 2013; Varmuza and Filzmoser, 2009; Lu et al., 2010; Yang et al., 2011; Manta et al., 2002; Guo et al., 2004; Song et al., 2006). Based on the presence of metals in the resulting groups (factors), these groups were identified as sources of PM.

2. Method of measurements and analysis

2.1. Study area

The monitoring station was situated in Žilina city centre and on Vojtech Spanyol Street. This street represents one of the arteries connecting the secondary and tertiary city ring roads and connects the city centre with the largest housing estate of Vlčince. This is reflected in the amount and frequency of traffic which passes along this city radial road. The traffic volume on certain days amounts to 15,000 vehicles/24 h. The adjacent buildings along the road include housing developments and the civil amenities and facilities. The buildings create barriers on both sides of the road. We can consider this bounded space to be a street canyon. The ventilation of the canyon is limited in two ways. There is often a large accumulation of pollution during bad weather conditions, which may include inversions and windless conditions, etc. Walkways for the pedestrians occupy both sides of the monitored road. The monitoring devices were situated close to the edge of the road.

2.2. Sample collection

Sampling of particulate matter was performed near the urban connecting route during 2010 (19–25 October), 2011 (8–14 March, 11–17 April, 7–14 July, 13–19 October), and 2012 (26 January–1 February, 16–22 April, 7–13 June). The goal was long-term monitoring of a representative sample of particulate matter in the atmosphere and its behaviour relative to environmental conditions. In the second phase of the research, a chemical analysis of the particulate matter was performed, as well as the determination of its possible sources.

To establish the amount of particulate matter present in the ambient air, a reference method (the gravimetric method) was applied, pursuant to the standards of STN EN 12341 (2016). The sampling was performed using low volume flow samplers (LECKEL LVS3, Low Volume Samplers). In total, 3 pieces were used. Three fractions of particulate matter were monitored concurrently, specifically PM_{10}, $PM_{2.5}$ and PM_1. The coarse fraction $PM_{2.5-10}$ was determined as the difference between fractions PM_{10} and $PM_{2.5}$, and the $PM_{1-2.5}$ fraction was determined as the difference between fractions $PM_{2.5}$ and PM_1. Particulate matter was collected on nitrocellulose filters having a diameter of 47 mm at a fixed airflow rate of 2.3 #Nm^3/h (normal cubic meters per hour) under standard conditions of 101.325 kPa and 0 °C, and then the mass of particulate matter collected on the filters was determined. All filters used were conditioned at 20 °C and 48.2% RH prior to sampling, as well as after sampling and weighing (STN EN 12341, 2016). The particulate matter was sampled on the filters for 16 h during daytime sampling (6 am–10 pm) and for 8 h during night sampling (10 pm–6 am). The filters were changed in the samplers twice every 24 h (at 6 am and at 10 pm). At the end of sampling, we had 108 samples of each PM fraction eligible for further analysis. Alongside the monitoring of PM, basic meteorological data were observed as well, including temperature, ambient humidity, speed and direction of wind, and precipitation.

2.3. Sample preparation and analysis

The particulate matter contains various elements and compounds. In the next phase of the research, we concentrated on the measurement of the selected metals found in the fractions PM_{10}, $PM_{2.5}$ and PM_1. We focused on monitoring 17 metals