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Research article

Modeling the carbon monoxide dissipation in Timisoara, Romania

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ABSTRACT

Modeling the evolution of pollutants' concentration is important for predicting their impact on the human health and implementing measures for a sustainable development and environmental protection. Since the carbon dioxide (CO) is one of the main pollutants that affect the urban environment, the present study aimed at building a model for the evolution of the mean daily and monthly concentration in Timisoara, Romania. We found a non-linear direct dependence of CO concentration on the temperature and humidity and an inverse proportional relationship with the wind speed. The models have been linearized and validated by statistical tests. The extreme values distributions have also been detected, and comparisons of the data with the admissible values are provided.

1. Introduction

Nowadays, it is hard to think that we could live without modern transport facilities. The society is facing the major issue of roads' agglomeration in the large urban centers because the cities have not been designed for today's traffic. The primary source of air pollution in urban areas remains the emissions resulted from the fuels' combustion in the vehicles' engines. On the other hand, a significant contribution is that of the incorrect placement and operation of old heating units or industries that require refurbishment (Aggarwal and Jain, 2015; Goyal and Chalapati Rao, 2007; Liang et al., 2016).

For predicting the environmental pollution, different mathematical models have been built. According to the European Environment Agency, 142 dispersion models have been developed and accepted for Europe, for monitoring and reducing the pollution at the global scale. The atmospheric dispersion models can be classified in: deterministic (Gauss model, Euler model and Lagrange model), semi-empirical, stochastic models, the chemical model, and the receptor model (Moussiopoulos, 1997).

Roy et al. (2015) presented two approaches that explain the linkage between the source and receptor. They are source-oriented or receptor-oriented. Atmospheric Dispersion Model (AERMOD) and ISC-AERMOD belong to the first category. For explaining the pollutants dynamics, researchers used different dispersion models as ISCST3, ADMS, CALINE4, AERMOD, most of them being based on the assumption of a steady-state regime and of a linear trajectory of pollutants in space and time (Shiva Nagendra et al., 2016). The Gaussian dispersion model has been implemented in AERMOD for calculating the concentration of air pollutants related to their transport, while the CALPUFF has been used for modeling the atmospheric conditions (Ainslie and Jackson, 2009; Pan et al., 2016). Other authors utilized the Principal Component Analysis (PCA) for identifying the possible sources of pollutants (Chang and Lee, 2008).

Multiregional input-output models have also been proposed. We mention the structural decomposition analysis (SDA) of variations of emissions (Deng et al., 2016), an approach based on Hidden Markov Models (Gomez-Losada et al., 2016), PMF and ME2 models (Liu et al., 2016), the Semi-Empirical Urban Street (SEUS) model (Venegas et al., 2014). Wang et al. (2016) have shown that the models based on the dispersion algorithms OSPM, CALINE 4, and SIRANE exhibited poor correlation with near-road pollutants' concentrations and were able to simulate better the average concentrations occurring along the roads rather than the range of concentrations measured under various conditions.

One of the main pollutants that affect the air quality is the carbon monoxide (CO). At the ambient temperature, CO is a colorless and odorless gas, with 192 °C boiling point, 207 °C melting point, 0.97 kg/m^3 vapor density, and the flammable (explosive) limits in the air of 12.5–74.2%. CO results mainly from incomplete

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combustion of fossil fuels (wood, coal, charcoal, oil, paraffin, propane, natural gas and trash). CO can accumulate in the Earth's atmosphere to dangerous levels, especially during the period of atmospheric calm in winter and spring, when people burn more fossil fuels for heating. The atmospheric calm is the most favorable meteorological condition for the air pollution due to the pollutants accumulation in the vicinity of their source, and the progressively increasing of their concentrations.

CO participates in chemical reactions that give photochemical smog, as follows:

$$^{\bullet}OH + CO \rightarrow {}^{\bullet}HOCO \quad (1)$$

$$^{\bullet}HOCO + O_2 \rightarrow HO_2^{\bullet} + CO_2 \quad (2)$$

$$HO_2^{\bullet} + NO \rightarrow {}^{\bullet}OH + NO_2 \quad (3)$$

$$NO_2 + h\nu \rightarrow NO + O(^3P) \quad (4)$$

$$O(^3P) + O_2 \rightarrow O_3, \quad (5)$$

where $h\nu$ is the photon of light that is absorbed by the molecule of NO_2.

From (1) it results that in reaction with a hydroxyl radical ($^{\bullet}OH$), CO produces a radical ($^{\bullet}HOCO$) that transforms into carbon dioxide (CO_2) and a new radical, $HO_2^{\bullet}$ (Equation (2)), in the presence of oxygen (O_2). At its turn, $HO_2^{\bullet}$ reacts with nitrogen oxide (NO). The result of the reaction (3) is the nitrogen dioxide (NO_2), that is involved in the process of ozone formation, via photolysis ($h\nu$), as described in Equations (4) and (5) (Myriokefalitakis et al., 2016; Reeves et al., 2002; Bergamaschi et al., 2000).

Even if the primary anthropogenic sources of CO emission are associated with the combustion processes (transport, heating, industrial and biomass burning), huge CO amounts result from the oxidation of methane and non-methane hydrocarbons. CO accumulated in large quantities in small areas generates chain reactions and atmospheric movements due to its persistence, which can vary from weeks (in the middle atmosphere) to months (in troposphere and mesosphere). Carbon monoxide produced by natural sources is quickly dispersed over a large area, without putting at risk the human health.

CO is a toxic gas, which becomes fatal in high concentrations (about 100 mg/Nm^3) by reducing the capacity of the blood to carry oxygen, with consequences on the respiratory and cardiovascular system. At relatively low concentrations, CO affects the central nervous system, weakens the heart rate, lowers the blood volume distributed in the body and reduces the visual acuity and physical ability. A short exposure to CO can cause acute fatigue, breathing difficulties and chest pain to the people with cardiovascular disease, determine irritability, headaches, rapid breathing, lack of coordination, nausea, dizziness, confusion and significantly reduces the attention. The people most affected by CO exposure are children, elders, and people with respiratory and cardiovascular diseases, anemic individuals and smokers.

As consequence of the traffic's growth during the last ten years, the emissions and thus, the resulted immissions, represent a constant concern of specialists in the field of environmental protection in Romania. Their studies are primarily related to the pollution in the metropolitan areas and the developed regions of the country, as well as the comparisons with other urban zones in the world (Masiol et al., 2017; Wang et al., 2014; Zeng et al., 2017). Timisoara is one of the cities frequently monitored in Romania, due to the reduced ability of the municipal infrastructure to absorb the vehicular traffic and a major increase in the number of vehicles in the last 15 years (from 95 to 370 cars per 1000 residents). Therefore, we witness daily traffic congestion and delays on the main roads of the city (Popescu et al., 2011).

Estimating the emissions from the movement sources of road vehicles is the first step in evaluating their impact on the ambient air quality and human health. Some studies have quantified the emissions of the vehicles in Timisoara. Popescu and Bisorca (2003) reported very high values of CO concentration (over 18 mg/Nm^3 at different street crossings) during the period 2001–2004. Ionel et al. (2008) reported an average specific emission factor for different crossroads of about 0.00011 mg/(Nm^3·m^2) per day, respectively of 0.00076 mg/(Nm^3·m^2) per night. In 2003, the CO emissions recorded in different municipal road junctions represented approximately 85% of the recorded emissions, as a consequence of the use of old cars, buses with diesel engines and of secondary emission factors from various sources.

In 2011, CO generated by the road traffic in Romania represented 16% of all emissions produced by this pollutant (compared to only 4% that came from the industrial sector) registered at the national level and presented in a report by the European Environment Agency (EEA, 2013). Between 2011 and 2014 the emissions of CO and non-methane volatile organic compounds (NMVOCs) have been significantly reduced.

Statistics show that in municipalities located in the southern and south-eastern Romania (e.g. Bucharest) the transport sector contributes to the CO accumulation with relatively high rates (50–60%) (Apascaritei et al., 2009; Iorga et al., 2015). These values are significantly smaller than those recorded during the period 2003–2006. The monthly average concentration of CO recorded between January 2008 and June 2009 in the northern part of the Romanian Littoral was of 6.612 mg/Nm^3, smaller than the maximal mean value accepted by the European Legislation for 8 h (Barbulescu and Barbes, 2013, 2014, 2015). In the same region, the measured CO concentration was below 6 mg/Nm^3 and only occasionally it increased over 8 mg/Nm^3 during 2005–2007 in some monitored urban or industrial areas near Constanta (Barbes et al., 2009).

In this context, the objectives of our study are: modeling the dependence of the pollutants' concentration on the atmospheric conditions, estimating the distribution of the extreme concentration of CO, and analyzing the maximum values of CO's concentration and comparison with those given in the EU normative.

2. Data and methods

2.1. Site description and data

Timisoara is situated at 45°44′ northern latitude and 21°13′ eastern longitude and is considered to be the most dynamic city in Romania in economic terms and the best business city. The climate in this area is temperate-oceanic (humid – continental), characteristic of the southeastern part of the Pannonian basin, being influenced by the cyclonic movement from the Mediterranean and Adriatic Seas. There are no high differences between the extreme temperatures, the coolest month being January and the warmest July. The precipitation is roughly uniformly distributed over the year, the lowest quantity being recorded in February and the highest in June (about 44.5 mm and 91 mm, respectively).

The geographical position determines the specific elements of the natural and human potential and influences its relations with other cities from Romania and the main urban poles of Europe, being situated at less than 700 km from 15 European capitals. Timisoara is located at the connection of two European and four national roads, is a big railway center and is served by the third busiest international airport in Romania.

Located at 571 km from the capital (Bucharest), Timisoara is the

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