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An integrated low-cost road traffic and air pollution monitoring platform to assess vehicles' air quality impact in urban areas

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Abstract

An integrated monitoring platform (IMP) was developed for real-time monitoring of traffic flows and related air pollution in urban areas. The IMP includes: (i) an air quality monitoring unit, integrating the "Arduino" open-source technology with low-cost and high-resolution sensors, to measure air pollutant concentrations; (ii) a traffic monitoring device, equipped with a camera sensor and a video analysis software, to detect vehicles' counts, speed and category; (iii) a spatial data infrastructure, composed of a central GeoDatabase, a GIS engine, and a web interface, for data storage and management. The IMP was tested in Florence (Italy) by installing sensor devices at a road site where a 1-year measuring campaign was carried out. A reference meteorological station in the city centre was used to provide observations of wind speed and direction, air temperature, and relative humidity.
In this work, a statistical analysis was performed to investigate the influence of local road traffic and meteorological conditions on CO, NO_2 and CO_2 concentrations. Two different methods were applied: a linear regression model and an artificial neural network. To investigate the role played by emissions from road traffic, the influence of all drivers by period of the year (cold vs. warm months) and day of the week (weekdays vs. weekends) was analysed. As a result, the contribution of local road traffic on pollutant concentrations proved to be lower than meteorological parameters.

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Keywords: Urban air pollution; Integrated monitoring platform; Low-cost sensors; Road traffic air quality impact; Statistical models.

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1. Introduction

Environmental impacts are particularly severe in urban areas due to high population, traffic levels, intense vehicle use, driving patterns, vehicle characteristics and complex urban geometry (Mishra et al., 2016). In the past decades, regulations worldwide have progressively imposed more and more restrictive thresholds for air pollutant concentrations. This has led to improvements in road transport sector, e.g. promotion of public vs. private transport, vehicle fleet turnover, fuel improvement, or increase in electric/hybrid vehicles share (Gualtieri et al., 2014), resulting in considerably reduced air pollutant emissions. In Europe, road transportation sector accounts for total annual emissions by 40% for NO_x, 23% for CO, 13% for primary $PM_{2.5}$, 9% for primary PM_{10}, and 11% for VOCs. Shares rise to 23% for total PM_{10} and 28% for O_3 precursors if emissions from precursors of secondary aerosol and O_3 are also considered (EEA, 2017). Today, mobility managers and city administrators are strongly committed in analyzing and taking actions to tackle air quality limit exceedances. To this goal, a clear support might arise from availability of monitoring devices – at the same urban site – of air pollutant concentrations and traffic flows. With this in mind, within a previous study (Zaldei et al., 2017) an integrated monitoring platform (IMP) was developed for real-time monitoring of traffic flows and related air pollution. The IMP was tested in Florence (Italy) by installing sensor devices at a road site where a 1-month measuring campaign was carried out.

The goal of the current work is twofold: (i) to analyze the results of a 1-year campaign carried out by the IMP installed at the same road site in Florence; (ii) to investigate the influence played by local road traffic and meteorological conditions on CO, NO_2 and CO_2 concentrations. As for (ii), two different statistical methods were applied: a linear regression model and an artificial neural network (ANN). The analysis has been performed by period of the year (cold vs. warm months) and day of the week (weekdays vs. weekends).

2. Material and methods

2.1. Description of the integrated monitoring platform

The developed IMP includes: (i) an air quality monitoring unit, integrating the "Arduino" open-source technology with low-cost and high-resolution sensors, to measure CO, NO_2 and CO_2 concentrations; (ii) a traffic monitoring device, equipped with a camera sensor and a video analysis software, to detect vehicles' counts, speed and category; (iii) a spatial data infrastructure, composed of a central GeoDatabase, a GIS engine, and a web interface, for data storage and management. Full description of all IMP specifications may be found in Zaldei et al. (2017).

2.2. Road site and experimental data

The IMP was installed at Via della Villa Demidoff, a road located within a densely inhabited area of the city of Florence (Italy). All details upon this study area have been provided in Zaldei et al. (2017). Herein a 1-year monitoring campaign (01/02/2016 to 31/01/2017) has been carried out to measure 1-h concentrations of CO, NO_2 and CO_2, as well as traffic flows (F) and vehicle speed (V). The Ximeniano reference meteorological station, located in the city centre, was used to provide 1-h observations of wind speed (WS) and direction (WD), air temperature (T), and relative humidity (RH). The cold vs. warm months disaggregation was based on actual heating regulations in Florence: (i) 1 Nov. to 15 Apr. (cold months); (ii) 16 Apr. to 31 Oct. (warm months).

2.3. Statistical analysis

All procedures were carried out in "R-stat" environment (R Core Team, 2017).

The pattern of NO_2 and CO_2 concentrations has been analyzed by using the "PolarPlot" function implemented in the "Openair" R package (Carslaw, 2015). This function draws bivariate plots of concentrations, shown in polar coordinates, varying by wind speed and direction. It provides a very useful graphical technique for identifying and characterising different pollution sources, and assessing the joint wind speed-direction concentrations dependence.

A linear regression model and an ANN have been applied to investigate the influence of local road traffic and meteorological parameters on NO_2 and CO_2 concentrations. Both statistical methods were only trained, using the