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Innovative low-cost air quality stations as a supporting means for road traffic regulations in urban areas

L. Brilli¹, A. Berton³, F. Carotenuto¹, B. Gioli¹, G. Gualtieri¹, F. Martelli¹, S. Profeti², G. Trombi⁴, C. Dibari⁴, M. Moriondo⁴, C. Vagnoli¹ and A. Zaldei^{*1}.

¹National Research Council-Institute of Bioeconomy (CNR-IBE), Via Madonna del Piano 10, 50019 Sesto Fiorentino, Italy

²Università di Pisa, Dipartimento di Ricerca Traslationale N.T.M.C, Via San Zeno 35, 56123 Pisa, Italy

³CNR-IFC, Via Giuseppe Moruzzi 1, 56124 Pisa, Italy

⁴Università di Firenze, Dipartimento di Scienze e Tecnologie Agrarie, Alimentari Ambientali e Forestali, P.le delle Cascine 18, 50144 Firenze, Italy

Email: a.zaldei@ibimet.cnr.it (A.Zaldei)

Abstract. Air pollution is currently one of main issues affecting urbanized areas worldwide. Industrial activities, road traffic and heating systems are main emission sources significantly increasing the levels of atmospheric pollutants as particulate matter, ozone, and nitrogen oxides. Local administrations monitor these harmful gases by means of reference monitoring stations provided by regional/national environmental protection agencies. These stations, however, have limitations due to the little presence over the whole municipality, low time-frequency, and high costs. In this framework, CNR-IBE, University of Florence – Department of Agriculture, food, environment, and forestry (DAGRI), Tuscany Region Environmental Protection Agency (ARPAT) and epidemiologists of the Pisa University agreed an initiative to create an environmental “living lab” aimed at assessing the impacts due to anthropogenic activities on air quality and thus on population exposure. Two study areas located in the Tuscany region (Italy) were chosen: the rural town of Capannori, and the city of Florence. The town of Capannori was selected since it lies within a critical area both affected by a variety of emission sources and winter weather conditions unfavourable to pollutant dispersion. The city of Florence was chosen for assessing air quality in urban areas following a possible traffic reduction due to creation of new urban tramway lines. The air quality analysis was carried out by means of a monitoring network comprising innovative low-cost stations (named AIRQino). PM concentrations were mainly considered for providing indicative air quality measurements. The preliminary results indicated that: i) low-cost stations, after calibration and validation against more than one-year observations from a reference air quality station, confirmed their reliability in measuring air quality data; ii) AIRQino data can supplement air quality information from reference stations and may be used to help traffic regulation actions at urban scale.

Keyword: Air quality; Urban area; Low-cost stations; PM concentrations; Road traffic.



1. Introduction

During the last 20 years, mostly as a result of vehicle technology improvement and the major vehicle renewal [1], the transport sector has considerably reduced its air pollutant emissions in Europe [2]. Road transportation still remains a great concern for air quality in urban areas, however, contributing to total annual emissions in Europe by 46% for NO_x, 23% for CO, 15% for primary PM_{2.5}, 12% for primary PM₁₀, and 10% for nmVOCs [2,3]. Looking at the Italian context, according to the nationwide emission inventory [4] this sector provides annual emissions by 49.5% for NO_x, 22.7% for CO, 18.7% for nmVOCs, 12.2% for primary PM₁₀, and 11.8% for primary PM_{2.5}. To provide adequate information on air quality spatial distribution, fixed measurements by reference monitoring stations provided by regional/national environmental protection agencies are mandatory as agreed by the enforced 2008/50/EC EU Directive [5] directive. However, to overcome issues related to limitations due to the bare presence over the whole municipality, low time-frequency, and high costs, these measurements should be integrated with air quality analysis carried out by means of a further but lower-cost monitoring network. In this framework, CNR-Ibimet, University of Florence – Department of Agriculture, food, environment, and forestry (DAGRI), Tuscany Region Environmental Protection Agency (ARPAT) and epidemiologists of the Pisa University agreed to an initiative to create an environmental “living lab” aimed at assessing the impacts due to anthropogenic activities on air quality and thus on population exposure. Two study areas both located in the Tuscany region (Italy) were chosen: the rural town of Capannori and the city of Florence. Capannori was chosen since it lies within a critical area both affected by a variety of emission sources (highway, combustion plants for paper transformation, agricultural biomass burning) and winter weather conditions unfavourable to pollutant dispersion (low wind regime, stable atmospheric conditions, etc.). Florence was chosen for assessing air quality in urban areas after the traffic reduction due to the creation of new tramway lines. The air quality analysis was carried out by means of a monitoring network comprising innovative low-cost stations (named AIRQino) equipped with sensors for collecting air pollution (PM_{2.5}, PM₁₀, NO₂, O₃, CO) and meteorological parameters (air temperature and relative humidity). Specifically, two AIRQino stations (SMART15 and SMART19) were deployed at Capannori, calibrated against one-year observations (19/01/2018 – 21/12/2018) from a reference air quality station managed by ARPAT and then validated using data collected from the same reference air quality station but across wintertime (21/12/2018 - 07/03/2019). Three AIRQino stations (SMART27, SMART28 and SMART29) were also calibrated at CNR-IBE according to the methodology proposed for Capannori using the DUST-TRACK as reference station and then deployed for 30 days (June 2019) in Florence at three different roads. Concentrations of PM were mainly considered for providing indicative air quality measurements to supplement fixed measurements collected by the official urban monitoring network.

2. Materials&Methods

2.1. Study areas

Two study areas were chosen for assessing performances of low-cost air quality monitoring stations.

- a) Florence, the largest city in Tuscany with a total of 1,500,000 inhabitants if considering its metropolitan area, is affected by a wide variety of emission sources typical of a large city (highway, local roads, industries, etc.). Its geographical position (43°46' N, 11°15' E) within a valley surrounded by hills, as well as its weather conditions across the year, result in unfavourable pollutant dispersion conditions, therefore making it a meaningful case study for addressing a comprehensive air pollution monitoring. Also, the recent development of a new tramway line further put to the fore the need for monitoring air quality levels and changes due to road traffic reduction.
- b) Capannori, close to the city of Lucca, is a small rural town (46,000 inhabitants). It lies within a critical area (43°52' N, 10°34' E) affected by a variety of emission sources (highway, local roads massively travelled by heavy-duty vehicles, combustion plants for paper transformation,

agricultural waste burning including biomass burning) and winter weather conditions unfavourable to pollutant dispersion (low wind regime, stable atmospheric conditions, shallow thermal inversions, etc.).



Fig. 1. Geographical location of the two study areas: a) Tuscany region in Italy; b) location of the two study areas of Capannori (yellow square) and Florence (red square); c) view of Florence; d) view of Capannori.

2.2. Description of the air quality unit: “AirQino”

The air quality monitoring unit named AIRQino (Fig. 1a) was developed within the national SMARTCITIES project [6,7]. The unit is mainly based on an Arduino Shield Compatible electronic board equipped with low-cost and high-resolution sensors. Sensors installed provide measurements of meteorological parameters (air temperature and relative humidity), and concentrations of pollutants (PM_{2.5}, PM₁₀, NO₂, O₃, CO). The board integrates a microprocessor acquiring all readings from the installed sensors which, in turn, transmit geolocated data to a data server connected to the applications and web server. This method allows a real-time visualization on a web browser of the measures. Processes of sensors' calibration and validation was performed following [8] and the calibration protocol of low-cost sensors developed by the Joint Research Centre [9], respectively.



Fig. 2. Pictures of: (a) the inside of AirQino monitoring unit; (b) the integrated circuit board and (c) the AirQino monitoring unit as found in the areas of analysis.

3. Results and discussion

3.1. AirQino calibration

Two AIRQino stations (SMART15 and SMART19) were deployed at Capannori close to a reference air quality station managed by the Tuscany Region Environmental Protection Agency (ARPAT). One-year observations (19/01/2018– 21/12/2018) were used for calibrating both stations. In order to improve the accuracy of the measurements and assessing sensor response, both PM_{2.5} and PM₁₀ concentrations were assessed. As observed in Fig. 3, both PM_{2.5} and PM₁₀ concentrations of the two AIRQino stations (SMART15 and SMART19) fit quite well those from the reference ARPAT station, not only in terms of overall pattern but also of magnitude. This result is also confirmed by simple statistics (PM_{2.5}: SMART15, $R^2=0.86$ and SMART19, $R^2=0.81$; PM₁₀: SMART15: $R^2=0.81$ and SMART19: $R^2=0.77$).

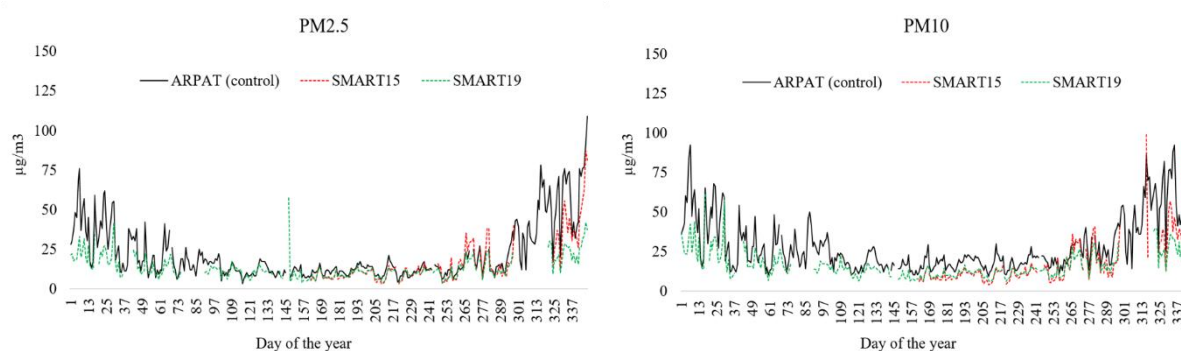


Fig. 3. Calibration of PM_{2.5} and PM₁₀ concentrations measured by AIRQino stations using one-year observations against data from ARPAT reference air quality station.

3.2. AirQino validation

Validation of AIRQino stations was performed using data collected from the same reference air quality station but across a different time period, i.e. between 21/12/2018 and 07/03/2019. This three-month wintertime period, usually characterized by large emissions from heating plants, road traffic and biomass burning, enabled to evaluate capability of AIRQino stations to capture the strongly-varying patterns typical of this period. As observed in Fig. 4, both PM_{2.5} and PM₁₀ concentration patterns and magnitudes of the two AIRQino stations fitted quite well those from the reference station (PM_{2.5}: SMART15, $R^2=0.85$ and SMART19, $R^2=0.61$; PM₁₀: SMART15: $R^2=0.79$ and SMART19: $R^2=0.55$).

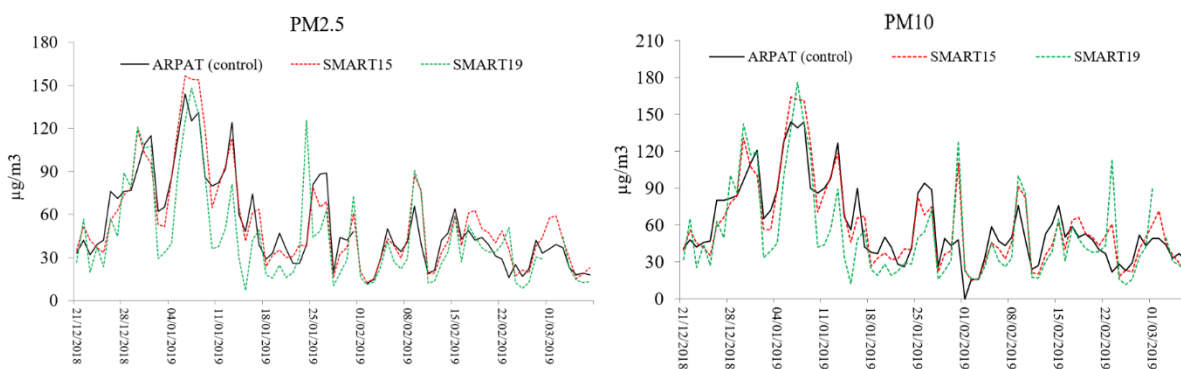


Fig. 4. Validation of PM_{2.5} and PM₁₀ measured by AIRQino stations (21/12/2018–07/03/2019) against data from ARPAT reference air quality station.

3.3. AirQino application: Florence case study

Three AIRQino stations (SMART27, SMART28 and SMART29) were also calibrated at CNR-IBE according to the methodology proposed for Capannori using the DUST-TRACK as reference station. The three stations named SMART27, SMART28 and SMART29 were then deployed in Florence at three different roads. The stations were located precisely over tram stations, which continuously provide energy supply which should guarantee reduced data losses. Data collection is still ongoing. However, for simplicity, only the pattern of June 2019 is reported. This heating-free period of the year is usually characterized by low emissions of road traffic while relevant photochemical activity leading to typically high concentrations of ozone and nitrogen oxides. In addition, this deployment allowed to collect air quality data in areas previously characterized by intensive road traffic, thus providing information on the current pollutant level which may be then compared against those in areas where the traffic is still intense and tram line is missing.

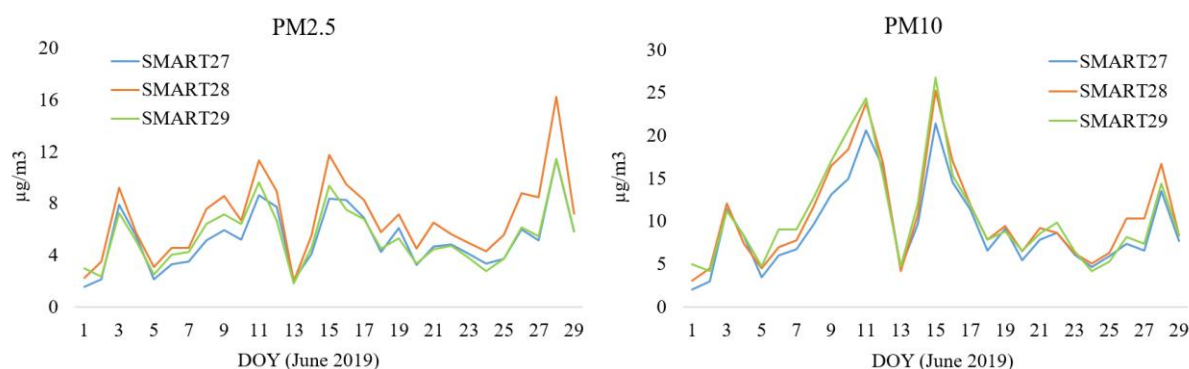


Fig. 5. Patterns of PM_{2.5} and PM₁₀ concentrations (June 2019) over tram stations along three different roads of Florence.

4. Conclusions and perspectives

Developed for measuring real-time air pollution in urban areas, AIRQino stations were calibrated and validated against more than one-year observations at Capannori and also tested through a 1-month campaign at three roads in Florence (Italy). Concentrations of PM were mainly considered for providing indicative air quality measurements. AIRQino stations can be installed over a number of key roads of the urban area so as to create an efficient network of low-cost “supplementing” air quality stations. Monitoring performed through AIRQino stations proved to be a sustainable and reliable approach which may be used to help traffic regulation actions at urban-scale (e.g. traffic restrictions, odd-even days, etc.). In a future perspective AIRQino, thanks to its easy-to-be-managed, may be also a valid tool which could be directly used by citizens in the view of participatory environmental monitoring and city management. AIRQino’s open-source modular structure makes it easy to implement various upgrades, which are already expected in the near future, (e.g. integration of further air pollutant sensors, improved calibration methods, etc.).

Acknowledgments

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