Environmental Pollution xxx (2017) 1–8

Contents lists available at ScienceDirect

Environmental Pollution

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

An empirical model to predict road dust emissions based on pavement and traffic characteristics☆

Elio Padoan [a, b, *], Franco Ajmone-Marsan [a], Xavier Querol [b], Fulvio Amato [b]

[a] Dipartimento di Scienze Agrarie, Forestali e Alimentari (DISAFA), Università Degli Studi di Torino, Largo Paolo Braccini 2, 10095 Grugliasco, TO, Italy
[b] Institute of Environmental Assessment and Water Research (IDÆA), Spanish National Research Council (CSIC), C/ Jordi Girona 18-26, 08034 Barcelona, Spain

ARTICLE INFO

Article history:
Received 4 August 2017
Received in revised form
26 October 2017
Accepted 28 October 2017
Available online xxx

Keywords:
PM10
Non-exhaust
Resuspension
Macrotexture
Aggregate size

ABSTRACT

The relative impact of non-exhaust sources (i.e. road dust, tire wear, road wear and brake wear particles) on urban air quality is increasing. Among them, road dust resuspension has generally the highest impact on PM concentrations but its spatio-temporal variability has been rarely studied and modeled. Some recent studies attempted to observe and describe the time-variability but, as it is driven by traffic and meteorology, uncertainty remains on the seasonality of emissions. The knowledge gap on spatial variability is much wider, as several factors have been pointed out as responsible for road dust build-up: pavement characteristics, traffic intensity and speed, fleet composition, proximity to traffic lights, but also the presence of external sources. However, no parameterization is available as a function of these variables.

We investigated mobile road dust smaller than 10 μm (MF10) in two cities with different climatic and traffic conditions (Barcelona and Turin), to explore MF10 seasonal variability and the relationship between MF10 and site characteristics (pavement macrotexture, traffic intensity and proximity to braking zone). Moreover, we provide the first estimates of emission factors in the Po Valley both in summer and winter conditions. Our results showed a good inverse relationship between MF10 and macro-texture, traffic intensity and distance from the nearest braking zone. We also found a clear seasonal effect of road dust emissions, with higher emission in summer, likely due to the lower pavement moisture. These results allowed building a simple empirical mode, predicting maximal dust loadings and, consequently, emission potential, based on the aforementioned data. This model will need to be scaled for meteorological effect, using methods accounting for weather and pavement moisture. This can significantly improve bottom-up emission inventory for spatial allocation of emissions and air quality management, to select those roads with higher emissions for mitigation measures.

1. Introduction

Particulate matter (PM) emissions from road dust resuspension are an increasing concern for air quality and public health (Denier van der Gon et al., 2013; Amato et al., 2014a). The stricter PM emission standards adopted in Europe, with the EURO Directive, have brought now more attention to the non-exhaust particles from road traffic (i.e. road dust, tire wear, road wear and brake wear particles), for which emissions are not controlled, and their relative impact on urban air quality is increasing (Amato et al., 2014b; Barmpadimos et al., 2012). In Southern Spain, for example, Amato et al. (2104b) found decreasing contributions for motor exhaust ($p < 0.001$) of 0.4 (0.57–0.24) μg $m^{-3}year^{-1}$ from 2004 to 2011. Conversely, in the same period, road dust contributions to PM10 levels remained stable. Current estimates suggest that, in the European domain, non-exhaust vehicle emissions represent 70% of urban primary PM10 emissions since 2015 (Kuenen et al., 2014). Among non-exhaust sources, road dust resuspension has generally the highest impact in PM concentrations, however, a comprehensive assessment of road dust impact both in terms of pollutants

☆ This paper has been recommended for acceptance by Charles Wong.

* Corresponding author. Chimica Agraria e Pedologia, Dipartimento di Scienze Agrarie, Forestali e Alimentari (DISAFA), Università degli Studi di Torino, Largo Paolo Braccini 2, 10095 Grugliasco, TO, Italy.

E-mail addresses: elio.padoan@unito.it (E. Padoan), franco.ajmonemarsan@unito.it (F. Ajmone-Marsan), xavier.querol@idaea.csic.es (X. Querol), fulvio.amato@idaea.csic.es (F. Amato).

https://doi.org/10.1016/j.envpol.2017.10.115
0269-7491/

(dust, carbonaceous particles and metals) concentrations and health outcomes has been rare (Ostro et al., 2011). This is due to the lack of reliable emission factors (for source oriented models, Schaap et al., 2009), and the similarity of the chemical composition of road dust with other mineral sources (Amato et al., 2009). Moreover, experimental studies on road dust characterization generally found high variability of road dust loadings in space and time, suggesting the need of bottom-up inventories and improvement in the description of spatial and temporal variability. Spatial inequalities of air pollution levels have been in fact observed at the urban scale, mostly for PM10 and its coarser fraction, which is dominated by road dust resuspension. Time variability is crucial for epidemiological studies but information is lacking on the day-to-day and seasonal variability of emission factors. Some recent studies attempted to observe and possibly describe the spatio-temporal variability. In Scandinavian countries, the use of studded tires and road salting/sanding are predictor variables to estimate road dust loadings and the NORTRIP model has been successfully applied in order to predict both spatial and temporal variability of road dust loadings (Denby et al., 2013a; 2013b); while in Central and Southern Europe, where time-variability is driven by meteorology, in addition to traffic flow, several authors used the ON/OFF approaches to account for road moisture due to precipitation (Pay et al., 2011; Schaap et al., 2009). Amato et al. (2012) studied the day-to day variability of road dust suspendible fraction in one Spanish and one Dutch streets, observing relatively short recovery rates within 24 h and 72 h respectively, which is in agreement with the recovery of ambient air PM coarse curbside increment (Amato et al., 2011; Keuken et al., 2010). However, uncertainty remains on the seasonal variability of road dust emissions, which can be also affected by meteorological pattern (higher relative humidity in winter, higher drought in summer, intense Saharan dust intrusions in spring, for example). Concerning the spatial variability, the gap of knowledge is much wider. Several factors have been pointed out as responsible of road dust build-up (i.e. emission potential): pavement characteristics (texture, mineralogy, age (Amato et al., 2013; Denby et al., 2013b; China and James, 2012; Berger and Denby, 2011; Gehrig et al., 2010; Gustafsson et al., 2009; Räisänen et al., 2005), traffic intensity and speed, fleet composition (Bukowiecki et al., 2010; Liu et al., 2016), proximity to traffic lights, but also the presence of external sources (e.g. construction dust, unpaved areas, African dust deposition, etc.). However, no parameterization is available as a function of these variables. Moreover, to understand the impact of these predictors is also important for air quality management since remediation measures can be designed.

In this study, we present a simple empirical model able to predict road dust suspendible fraction and, consequently, emission potential, based on pavement macrotexture, traffic intensity and proximity to braking zone. This model is based on field measurement in the cities of Turin (Italy) and Barcelona (Spain), thus considering quite contrasting environments (Mediterranean and Continental) and aims to estimate the maximum emission factor for single roads (without considering the effect of meteorology); it could be, therefore, suitable for spatial allocation of emissions. Moreover, the article offers the first estimates of emission factors in the Po Valley (Italy), one of the most polluted regions in Europe, both in summer and winter conditions.

2. Methods

2.1. Study area

Four sampling campaigns were performed in the cities of Turin (Italy) and Barcelona (Spain), three in the summer period (June and September 2016 in Turin, August 2016 in Barcelona) and one in winter (January 2017, in Turin). The two cities under study have a common high density of vehicle emissions (among the highest in Europe) but different climatic conditions.

The Turin metropolitan area has a population of around 1.5 million inhabitants, and is the fourth most populous metropolitan area in Italy. The high car density (5300 veh km^{-2}) provokes (as sum of exhaust and non-exhaust) almost 40% of the total primary emitted PM10, the second most important source (after biomass burning), according to the regional inventory (IREA, 2010). Climate is classified as humid subtropical, with moderately cold but dry winters and hot summers, when rains are infrequent but heavy. Average rainfall is around 1000 mm per year (mostly concentrated in spring and autumn) and daily temperatures vary within 2–22 °C (monthly averaged; ARPA Piemonte, 2014). The city is located at the western end of the Po valley, surrounded by hills to the East and by the Alps to the North and West. Thus, the dispersion of pollutants is very low, as in all cities of the Po valley (Eeftens et al., 2012; Belis et al., 2011; Padoan et al., 2016), due to the very low wind speed and the thermal inversion occurring in wintertime. Consequently, EC air quality standards are not met. In 2016, for example, PM10 concentrations in the city center exceeded the EU daily limit value for 70 days (ARPA Piemonte, 2016).

The Barcelona greater metropolitan area has around 4 million inhabitants and, with ~1 million vehicles, has also one of the highest car densities in Europe (5900 veh km^{-2}). The city is located in the western coast of the Mediterranean basin, with a Mediterranean climate (mild winter and hot summers), and the scarce and infrequent precipitation (614 mm as mean from 2010 to 2015) facilitate the mobilization and resuspension of road-deposited particles. In Barcelona, traffic emissions are the most important pollution source of PM10, although other significant sources are mineral dust, shipping and industry (Amato et al., 2016). At urban background sites, annual PM10 concentrations due to the regional contribution are less than 30% of the total, while non-exhaust vehicle emissions contribute 17% (7 mg m^{-3}), with the total road traffic contribution calculated at 46% (Amato et al., 2009). Thus, controlling local sources is very important for attaining PM10 limit values. The exposure scenario is even more problematic considering that 56% of urban population live less than 70 m away from major roads (>10,000 vehicles day^{-1}).

2.2. Road dust sampling

The mobile fraction (able to be suspended under the applied airflow, 30 l min^{-1}) of road dust below <10 μm in aerodynamic diameter (MF10) was sampled by means of a field dry resuspension chamber consisting in a sampling tube, a methacrylate deposition chamber, an elutriation filter, where MF10 was separated, and a filter holder, where particles were collected (a picture is available in Supplementary Material, Fig. SM1). More details on the sampler can be found in Amato et al. (2009, 2011).

In Turin, sampling sites were selected in order to characterize different fleet conditions, pavements and traffic characteristics. To this aim, sites were chosen in residential, commercial and industrial neighborhoods and, at some sites, sampling was performed in both traffic directions. In Barcelona, sampling sites were chosen in a limited area, but on streets with different pavements and traffic conditions. In total, 72 filters were collected, characterizing 30 sites in Turin and 6 sites in Barcelona (a map of sampling sites is reported in Fig. SM2).

In order to ensure a complete re-establishment of the stationary conditions of dust loadings, all the samplings were performed after, at least, one week without precipitation.

Each MF10 sample was collected as in previous studies, from a 50 × 100 cm area with the wider side centered within the most-