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Multicriteria approach to interpret the variability of the levels of particulate matter and gaseous pollutants in the Madrid metropolitan area, during the 1999–2012 period

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HIGHLIGHTS

- Trends in ambient pollutants concentrations were analysed over 1999–2012.
- Environmental policies on air quality produced a beneficial effect in this period.
- Fuel consumption and anthropogenic activities diminished due to the economic crisis.
- To reduce future exhaust emissions Euro6/VI vehicle generation should be introduced.
- To reduce future PM non-exhaust emissions, the volume of traffic should be reduced.

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ABSTRACT

The evolution of the mean levels of particulate matter (PM) and gaseous pollutants recorded in the Madrid metropolitan area from 1999 to 2012, were investigated focussing on the impact of mitigation strategies and economic scenarios. Temporal trends have shown that SO_2, CO, NO, PM_{10} and NO_2 levels at Madrid kerbside and urban-background sites have been decreasing over the 1999-2012 period, with statistical significance. A small contribution to the annual decreasing rates of SO_2, NO and NO_2 obtained at these sites could be attributed to the reduction in the regional background levels. The reduction in the emissions of atmospheric pollutants from specific sources of the urban agglomeration, explained most of the annual decreasing rates obtained at the kerbside and urban-background sites. From 1999 to 2007 a reduction of the emissions from road traffic and residential heating was produced, as a consequence of the implementation of a number of management strategies promoted and adopted by European and national public administrations. In contrast, from 2008 to 2012 a deep decrease in fuel consumption and a reduction of construction-demolition and roadwork activities took place in the Madrid metropolitan area, as a consequence of the economic recession. The expected overcoming of the economic crisis within the next few years, will presumably give rise to similar levels of PM and gaseous pollutants as those existing previously to the crisis period. The introduction of new Euro 6/VI vehicles which emit considerably less NO_x than previous generation diesel vehicles, as well as the implementation of strategies aimed at reducing resuspended mineral dust from road traffic and construction-demolition activities are thus encouraged.

1. Introduction

Urban air pollution has become an environmental issue of public health concern (Nel, 2005; Pope and Dockery, 2006) being also the source of other problems such as damage to materials, cultural heritage, buildings and vegetation in and around the city (Akimoto, 2003). A considerable amount of new information indicates that

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the adverse effects on health of particulate matter (PM), O_3 and NO_2 in some cases occur at concentrations lower than those established as guidelines in Europe (REVIHAAP Project: Technical Report, WHO, 2013).

Managing urban air pollution requires efficient but also realistic abatement strategies, comprising a defined set of specific control measures (Vlachokostas et al., 2011). That is the reason why the selection of the most appropriate control measures for a specific urban area should be performed on the basis of updated information on the characteristics of this area in relation with its economic, environmental and social concerns.

During the two last decades a number of European Directives has been elaborated and implemented with the aim of improving the air quality (AQ) in the Member States territory (Querol et al., 2014). In addition to this, regional and municipality governments have adopted a number of local measures to abate air pollution. In these cases the scope and level of ambition varied widely among the different countries and regions.

In spite of these efforts, there is presently an important proportion of zones across Europe exceeding the AQ standards for the annual limit value of NO_2 (40 $\mu g/m^3$), the daily limit value of PM_{10} (50 $\mu g/m^3$, not to be exceeded more than 35 days per year) and the health protection objective of O_3 (120 $\mu g/m^3$, the maximum daily 8-h moving average, not to be exceeded in more than 25 occasions in a 3-years average) (EU Directive 2008/50/CE). The latest European Environment Agency report (EEA, 2013) shows that PM_{10} and NO_2 limit values are exceeded in Europe mostly at urban traffic sites. Otherwise there is a large proportion of European areas meeting the AQ limit values and objectives for CO, SO_2, $PM_{2.5}$ and metals (EEA, 2013).

Some recent studies have been published aimed at interpreting trends of air pollutants for different periods in European regions (Carslaw et al., 2011; Barmpadimos et al., 2012; Cusack et al., 2012; Salvador et al., 2012; Karanasiou et al., 2014; Querol et al., 2014). In spite of the fact that the periods of study, the pollutants analysed and the characteristics of the AQ monitoring sites varied among these studies, some common features on the variability of air pollutants, which will be discussed later, have been reported by them. Querol et al. (2014) highlighted that the interpretation of past AQ trends may yield very relevant results for planning further cost-effective actions. Bearing in mind this issue, this work analyses the evolution of the AQ of one of the most important centres of population, economic activity and pollutant emissions of southern Europe, the metropolitan area of Madrid, in response to the implemented abatement policies on emissions from anthropogenic activities and the change in economic scenarios produced over the 1999–2012 period.

2. Methodology

2.1. The study area

The Madrid metropolitan area is one of the most densely populated regions in Spain with more than 5 million inhabitants, including Madrid city and surrounding towns. It is located at the centre of the Iberian Peninsula, within an air shed (the Madrid Air Basin) bordered to the north-northwest by the Guadarrama Range 40 km from the metropolitan area and to the south by the Toledo Mountains (Fig. 1). Industrial activity consists essentially of light factories, as neither heavy industry nor big pollutant emission plants are located in this area. The Madrid plume can be considered as typically urban, fed by traffic emissions and by residential heating (Artíñano et al., 2004). Fuel used by the heating facilities comprises natural gas, gasoil, coal and, to a lesser extent, biomass, propane and butane (Balance Energético de la Comunidad de Madrid, 2012).

It should be taken into account that in urban areas the resuspension of road dust can be an important contributor of vehicle and construction-demolition related pollutants to ambient PM concentrations. In fact, road transport has become the main source of mineral dust and metals in large cities without influence of industrial emissions, due to non-exhaust emissions: road dust resuspension, brake abrasion and tyre wear (Amato et al., 2013 and references therein). In the case of Madrid city, Moreno et al. (2013) associated hourly profile concentrations of crustal components in PM_{10} and $PM_{2.5}$ recorded at an urban-traffic site, with traffic rush hour patterns and daytime construction-demolition activities.

Thus, it is clear that traffic emissions, both vehicle exhaust emissions and dust resuspension as well as those from residential heating provide by far the dominant source of PM and gaseous pollutants at the Madrid metropolitan area.

2.2. Data sets

Time series of daily mean PM_{10} and gaseous pollutants (NO, NO_2, CO, SO_2 and O_3) concentrations recorded at the automatic AQ monitoring network (AQN) sites located in the study area, were obtained from 1999 to 2012. The AQN managed by the Madrid municipality consists presently of 24 monitoring sites located in almost all the districts of the city. Otherwise, the Madrid Regional AQN contributes presently with 23 stations distributed throughout the Madrid province. Only homogeneous time series of pollutants from those stations with the best possible data coverage (daily data coverage >80% for all the period) which were not relocated in the period of study were analysed. These criteria must be taken into account when performing a trend analysis of long-term data of ambient air pollutants concentrations. Otherwise, the analysis of AQ trends can lead to wrong interpretations.

It should be noted that $PM_{2.5}$ concentrations were not available until the year 2004 and 2006 at some of the Madrid City AQN and the Madrid Regional AQN monitoring sites, respectively. The

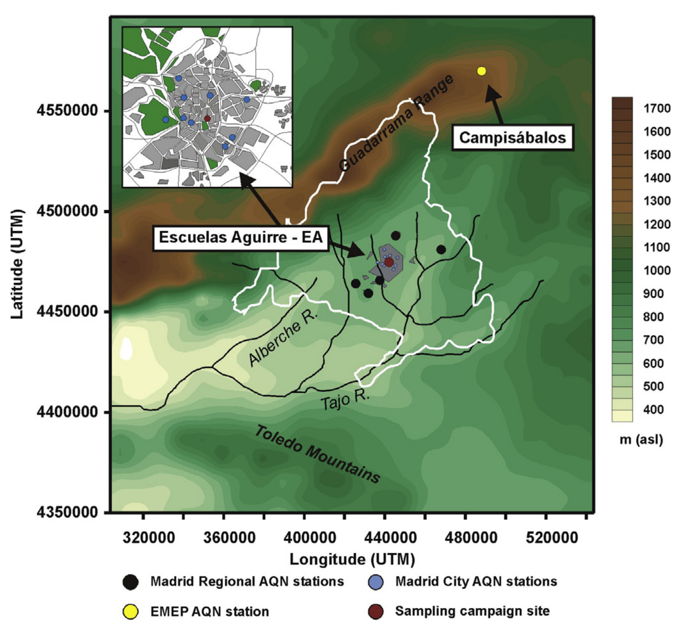

Fig. 1. Bi-dimensional topography and location of the Madrid Air Basin. The location of the monitoring stations of the Air Quality Networks and the Escuelas Aguirre (EA) monitoring site are shown. The metropolitan area, represented by the city of Madrid (up-left) and satellite towns has been shaded. White line represents the boundary of the Madrid province territory.