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Assessment of ultrafine particles and noise measurements using fuzzy logic and data mining techniques

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HIGHLIGHTS

- We focused on correlations of total number concentrations (TNC), traffic and noise.
- We apply a fuzzy logic and data mining computer tool.
- We proposed a means of estimating TNC from noise levels.
- Low cost sensors could be used as proxy for TNC monitoring in an air quality network.
- Air quality managers could decrease TNC by limiting the number of vehicles.

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ABSTRACT

This study focuses on correlations between total number concentrations, road traffic emissions and noise levels in an urban area in the southwest of Spain during the winter and summer of 2009. The high temporal correlation between sound pressure levels, traffic intensity, particle number concentrations related to traffic, black carbon and NO_x concentrations suggests that noise is linked to traffic emissions as a main source of pollution in urban areas. First, the association of these different variables was studied using PreFuRGe, a computational tool based on data mining and fuzzy logic. The results showed a clear association between noise levels and road-traffic intensity for non-extremely high wind speed levels. This behaviour points, therefore, to vehicular emissions being the main source of urban noise. An analysis for estimating the total number concentration from noise levels is also proposed in the study. The high linearity observed between particle number concentrations linked to traffic and noise levels with road traffic intensity can be used to calculate traffic related particle number concentrations experimentally. At low wind speeds, there are increases in noise levels of 1 dB for every 100 vehicles in circulation. This is equivalent to 2000 cm^{-3} per vehicle in winter and 500 cm^{-3} in summer. At high wind speeds, wind speed could be taken into account. This methodology allows low cost sensors to be used as a proxy for total number concentration monitoring in urban air quality networks.

1. Introduction

Road traffic is a dominant source of noise and air pollution in many cities (Fields et al., 2001; Foraster et al., 2011; Ross et al., 2011). The World Health Organization has recently classified air pollution as pertaining to group 1 (carcinogenic to humans) on the International Agency for Research on Cancer standard scale (Loomis et al., 2013).

Exposure to traffic-related air pollution and noise levels is more than just additive, as both have similar biological pathways, such as cardiovascular morbidity (Beelen et al., 2009; Allen et al., 2009; Davies et al., 2009), blood pressure and ischemic heart disease (van Kempen et al., 2002) or cognitive function in children (van Kempen et al., 2012). Recently, two studies have specifically correlated road traffic noise with respiratory (Tobías et al., 2014a) and cardiovascular mortality (Tobías et al., 2014b).

Researchers have shown a high degree of interest in studying the relationship between air pollutants and noise. Most have investigated the correlation between traffic-related noise and air pollution, focusing on gaseous pollutants, principally NO_2 and NO (Klæboe et al., 2000; Linares et al., 2006; Foraster et al., 2011; Ross et al., 2011; Kim et al., 2012), PM_{10} (Linares et al., 2006; Fung and Lee, 2011; Kim et al., 2012), $PM_{2.5}$ (Ross et al., 2011) and hydrocarbons (Ross et al., 2011;

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Kim et al., 2012). Some studies have focused on the correlation between noise and total number concentrations (TNC). For example, Weber (2009) investigates the spatio-temporal variation of particle number concentrations and ambient noise on the local scale within an urban residential environment close to a busy major road; Allen et al. (2009) study the spatial relationship between traffic-generated air pollution and noise in two US cities; Boogaard et al. (2009) compare real time exposure to particle numbers, fine particles and noise during car driving and cycling and Can et al. (2011) perform a correlation analysis of noise and ultrafine particle counts in a street canyon.

This paper presents a new approach for analysing air quality and noise. The proposed methodology is based on the use of the data mining tool PreFuRGe (Predictive Fuzzy Rules Generator) (Aroba, 2003). The tool proves to be efficient for modelling the qualitative behaviour of a complex system, and can also be applied to establish cause–effect relationships that, in contrast to classical statistical treatments, improve the understanding of the processes involved. PreFuRGe has allowed the discovery of new, very relevant (and sometimes hitherto unknown) information, using datasets drawn from various diverse contexts like for example: software engineering (Aroba et al., 2008), systems identification in control (Gegúndez et al., 2008) or modelling of complex environmental systems (Grande et al., 2010a,b). All the results obtained have been validated by experts in their respective fields, confirming the veracity and importance of the qualitative information generated by PreFuRGe.

The aims of this study are: (1) to evaluate the temporal variations of noise levels, total number concentrations, black carbon, gaseous pollutants, meteorological parameters and road traffic intensity in an urban environment; (2) to apply the PreFuRGe computational tool, thus enabling a qualitative interpretation of the database and (3) to determine the correlation between noise levels and particle number concentrations in order to test a method for estimating the particle number concentrations according to road traffic intensity.

2. Methodology

2.1. Study area

The study area is the city of Huelva (Fig. 1A), with around 150,000 inhabitants, located in SW Spain (Huelva: 37°15′0″N, 6°57′0″W, 54 m.a.s.l.). The city ring road is divided into two sections: the H-30, flanking the city to the north and east, and the H-31 which feeds from the H-30 into the A-49 motorway eastwards towards Seville. The average daily traffic in the two sections of the motorway is between 21,000 and 25,000 vehicles per 24 h. The University Campus monitoring station is situated on the northeast side of the city centre (Fig. 1A). The weekly mobility in the study area is distributed as follows: 44.9% private vehicles, 1.36% public transport and 51.9% pedestrians. *Avenida de Andalucia* (Fig. 1C), the closest main road to the monitoring station, consists of two 3-lane thoroughfares either side of central green areas and recreational sites and with two additional lanes reserved for car parking. It has a total width of around 80 m.

In addition, emissions from two industrial estates located to the south of the city (Fig. 1A) reach the city (De la Rosa et al., 2010; Fernández-Camacho et al., 2010a; Sánchez de la Campa et al., 2011) due to the predominance of the sea–land breeze during daylight hours (Castell et al., 2010). These two sources, road traffic and industrial emissions, contribute significantly to the particle number (PN), accounting for 50 and 44%, respectively (Fernández-Camacho et al., 2012).

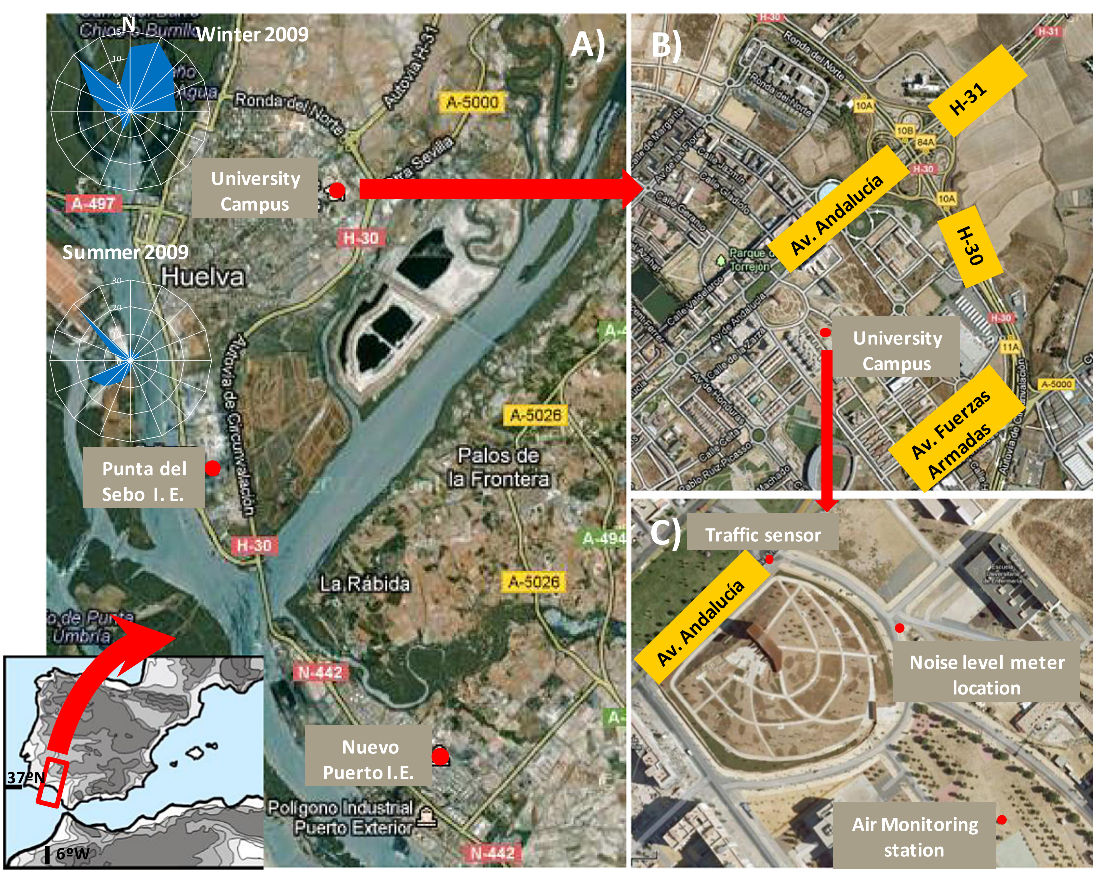

Fig. 1. A) Map of Huelva detailing, in addition to the university campus location, a wind rose for winter and summer 2009 and the two main Industrial Estates: Punta del Sebo and Nuevo Puerto. B) Main roads around the university campus. C) The university campus where the monitoring station and sound level meter location are highlighted.