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Air quality monitoring network design to control nitrogen dioxide and ozone, applied in Malaga, Spain

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ABSTRACT

Air monitoring networks are necessary to assess air quality in order to reduce pollution to levels which minimize harmful effects on human health and the environment. This paper describes a method to design or optimize air quality monitoring networks for nitrogen dioxide and ozone and its application in Malaga, a medium large city located in Andalusia, southern Spain, with traffic being the main source of air pollution. The completion of this method revealed that the old assessment network in Malaga was badly designed and made it possible to determine that one traffic-orientated and one background control station were necessary for NO_2 assessment in Malaga, as well as two control stations for O_3. First the number of stations necessary is obtained from historical data. Sampling campaigns with passive diffusion samplers at 74 sites were then carried out to obtain information on the pollution distribution in Malaga. The average concentrations found for NO_2 and O_3 were 22.8 μg/m^3 and 64.3 μg/m^3 respectively. Maximum values of up to 42.2 μg/m^3 NO_2 were found in Malaga city centre and O_3 reached 91.5 μg/m^3 downwind from the emission source. After spatial interpolation of the obtained values with Geographical Information Systems, a selection of the best locations for the monitoring stations was made, in line with the macro- and microscale siting requirements of the European Directive 2008/50/EC on ambient air quality and cleaner air for Europe.

1. Introduction

In order to obtain objective, reliable and comparable information on the air quality of a specific area, air quality monitoring networks are used, making it possible to take the requisite measures to protect the environment, to assess the results of such measures and to ensure that the public is properly informed about the state of the environment.

The approval and publication of Council Directive 1996/62/EC [1] on ambient air quality assessment and management and its daughter directives, 1999/30/EC [2], 2000/69/EC [3], 2002/3/EC [4] and 2004/107/EC [5], gave rise to an important change in air quality monitoring systems in Europe. Recently, in the interests of clarity, simplification and administrative efficiency, the above-mentioned European directives were replaced by the single Directive 2008/50/EC [6] on ambient air quality and cleaner air for Europe with no change to existing air quality objectives for nitrogen dioxide (NO_2) and ozone (O_3). With the aim of being as up-to-date as possible, references to the law will be made to Directive 2008/50/EC [6].

The present work describes a new method to design or optimize air quality networks, particularly to monitor nitrogen dioxide and ozone in compliance with the legislation. The proposed method consists of four steps for choosing the best locations for the monitoring stations: (1) preliminary evaluation; (2) sampling campaigns with passive diffusion samplers; (3) spatial interpolation; and (4) selection of best locations for the monitoring stations.

The first step in the optimization process is the preliminary evaluation of air quality based on historical data, which makes it possible to establish the minimum number and characteristics of the stations needed in each zone as set forth in Directive 2008/50/EC [6]. The location of the monitoring stations depends on the distribution of the contamination levels of pollutants, as the stations need to record representative levels for the entire zone. The second step consists of sampling campaigns. In this research, sampling campaigns with a large number of diffusive samplers were used to determine the concentration of nitrogen dioxide and ozone in the studied area.

A diffusion or passive sampler has been defined by the European Committee for Standardization as: "A device that is capable of taking samples of gases or vapours from the atmosphere at a rate controlled by a physical process such as gaseous diffusion through a static air layer or a porous material and/or permeation through a membrane, but which

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Table 1
Upper and lower assessment thresholds for nitrogen dioxide and oxides of nitrogen as expressed in Annex II of Directive 2008/50/EC [6].

	Hourly limit value for the protection of human health (NO_2)	Annual limit value for the protection of human health (NO_2)	Annual critical level for the protection of vegetation and natural ecosystems (NO_X)
Upper assessment threshold	70% of limit value (140 μg/m^3, not to be exceeded more than 18 times in any calendar year)	80% of limit value (32 μg/m^3)	80% of critical level (24 μg/m^3)
Lower assessment threshold	50% of limit value (100 μg/m^3, not to be exceeded more than 18 times in any calendar year)	80% of limit value (32 μg/m^3)	65% of critical level (19.5 μg/m^3)

does not involve active movement of air through the device" [7]. In a diffusion sampler, the gas molecules are transported only by molecular diffusion, which is a function of air temperature and pressure. This independence allows the time-weighted average ambient concentration to be calculated using Fick's laws of diffusion [7].

Diffusive sampling has been increasingly used for the assessment of environmental exposure to criteria pollutants, such as O_3, NO_2, SO_2, NH_3 and COV [8–12]. The benefits of passive sampling devices include simplicity of sampling, low operating costs, high correlation results as compared to continuous monitors, and deployment in areas where there is no electricity. A large number of units can be used simultaneously, gathering information on the spatial distribution of the pollutants. Diffusive sampling can be used if the average, instead of the real-time, pollutant concentration is adequate for the purpose of monitoring [11,13].

A wide variety of diffusive samplers has been developed since the first diffusive sampler for CO was patented in 1927 by Gordon and Lowe [14]. Diffusive samplers were not developed further until 1973 when Palmes and Gunnison published a description of the first diffusive sampler for SO_2, consisting of a glass cylinder of 1 cm in diameter and 3 cm long, using a diffusion barrier [15]. The diffusive sampler, commonly named Palmes tube, was developed later on and consisted of an acrylic tube 7.1 cm in length and 1.1 cm in diameter, containing a metal mesh coated with triethanolamine as an adsorbent for NO_2 [16,17]. Further changes consisted principally in modifications of the sampler dimensions and materials, diffusion barriers and the adsorbent for the gaseous pollutant [18–21].

To assign a contamination value to every point in the zone, spatial interpolations of the information obtained in the sampling campaign are made by use of Geographical Information Systems (GISs), which are becoming increasingly popular to estimate the distribution of environmental phenomena [22,23]. Also Directive 2008/50/EC [6] states that modelling techniques should be applied where possible to enable point data to be interpreted in terms of geographical distribution of concentration. The result map obtained by GIS is used to define the best sites for placing the control stations of the air quality monitoring network. In this last step for the design or optimization of the monitoring network a selection of the best locations for the NO_2 and O_3 sampling stations is made, obtaining a spatial distribution that ensures compliance with the location criteria established in the legislation.

Every few years, new sampling campaigns are carried out to verify the improvement of the optimized network and to make sure that the chosen locations for the stations are still representative of the air quality in the area.

The method proposed in this article for optimization of the design of air quality monitoring networks and its application to NO_2 and O_3 was carried out in Malaga. The city is located in Andalusia, in southern Spain, covers a superficies of 398.25 km^2 and has a population of 561,200 inhabitants. Years of drought cause the elevation of air pollution as pollutants are not washed out and its sunny climate favours the photochemical reactions that originate smog. Traffic is the most important source of air pollution in Malaga, followed by cements, limes and concretes and industry of non-metallic materials. The city is on its way to convert in a big city, augmenting traffic which induces more air pollution.

2. Materials and methods

The method developed in this study consists of four steps that make it possible to choose the best locations for the stations of the monitoring network, in compliance with the legislation. Additionally, a fifth step is included for verification of the optimized monitoring network.

2.1. Preliminary evaluation

This first step for optimising or designing an air monitoring network includes zonification, classification of the zones and determination of the minimum number of control stations needed.

The zonification of the study area consists in subdividing and classifying the territory into different zones with similar air quality. The division is based on studies of topography, population, economic activities, weather, land use, situation of nature parks and emission into the atmosphere. A zone with a population in excess of 250,000

Table 2
Minimum number of sampling points (for fixed measurement) needed for NO_2 and O_3 depending on the classification of the zone.

Population of agglomeration or zone (thousands)	NO_2		O_3		
	Maximum concentrations exceed UAT	Maximum concentrations between UAT and LAT	Agglomeration	Other zones (urban and suburban)	Rural background
0–249	1	1	–	1	1 station/50,000 km^2
250–499	2	1	1	2	
500–749	2	1	2	2	
750–999	3	1	2	2	
1000–1499	4	2	3	3	
1500–1999	5	2	3	4	
2000–2749	6	3	4	5	
2750–3749	7	3	5	6	
3750–4749	8	4	1 additional station per 2 million inhabitants		
4750–5999	9	4			
>6000	10	5			

Note: UAT = upper assessment threshold, LAT = lower assessment threshold.