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Levels and pedogeochemical mapping of lead and chromium in soils of Barcelona province (NE Spain)

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ABSTRACT

In this paper an analysis of the spatial distribution of Cr and Pb in topsoils in Barcelona province using 319 samples (approximately in a regular 5 km spaced grid) is presented. Ordinary kriging (OK) maps are obtained after examining and modelling observational variograms. A verification using cross-validation methods has been applied to evaluate the performance of the resulting maps for both Cr and Pb OK maps, which have also been compared to inverse distance weighting (IDW) interpolated maps, used as an additional benchmark. Both Cr and Pb OK maps have been obtained with better cross-validation scores in terms of median residuals and correlations between estimates and sampled values. Interpolated maps have been used to calculate the area of the province above a soil target threshold (Cr: 100 mg kg^{-1} and Pb: 85 mg kg^{-1})—higher intervention values were not observed. Target values corresponded to the 99.8 percentile for the Cr (9 km^2, 0.2% of the area of Barcelona province) and 92.7% percentile for the Pb (567 km^2, i.e. 7.2% of the province).

1. Introduction

The analysis of the spatial distribution of heavy metals in soils is of fundamental importance in a vast number of applications, including general soil surveying and characterization, delineation of potentially polluted spots at unsampled sites, or planning remediation strategies. The relevance of heavy metal soil pollution has favoured the application of advanced geostatistical techniques such as kriging in their different varieties (Goovaerts, 1997, 1999; Hengl and Heuvelink, 2004; McBratney et al., 2003; Rodríguez Lado et al., 2008; Webster and Oliver, 2001). Kriging techniques have also been widely applied in other earth sciences applications such as mapping of precipitation (Delhomme, 1978; Delrieu et al., 1988; Hevesi et al., 1992; Schuurmans et al., 2007), air temperature (Ishida and Kawashima, 1993; Stahl et al., 2006) or solar radiation (D'Agostino and Zelenka, 1992; Rivingtona et al., 2005) at different temporal and spatial scales.

Lead and chromium are among the usual heavy metals with potential toxicity present in soils (Kabata-Pendias and Mukherjee, 2007). Lead contamination is mainly related to exhaust gases from combustion engines during the last century (Cattle et al., 2002; Markus and McBratney, 2001) so it is typically found in topsoils in the neighbourhood of motorways and densely populated urban areas. Chromium pollution is frequently associated with leather tanning factories and the stainless steel industry and also in electro plating processes (Möller et al., 2005; Tarzia et al., 2002).

The purpose of this paper was obtaining high resolution spatial analysis maps of Pb and Cr concentrations in topsoils of Barcelona province (NE Spain). Previous studies have been conducted to examine in detail these heavy metal contents in some locations or the whole province of Barcelona such as Bech et al. (2005, 2006, 2008a,b) or Tume et al. (2006, 2008), but to date no spatially analysed map using geostatistical techniques has been published specifically for Pb or Cr for this province to the best knowledge of the authors, though other neighbouring areas such as the Ebro valley have been studied (Rodríguez et al., 2008; Rodríguez Martín et al., 2006). Spatially analysed maps provide concentration estimates at unsampled sites and, therefore, allow delineating potentially polluted locations and areas (i.e. estimated area above a given concentration threshold).

2. Materials and methods

2.1. Region of study

In this study, 316 topsoil samples (0–20 cm) located approximately in a 5 km regular grid covering Barcelona province have been examined. Fig. 1 shows the location of Barcelona province in Spain, Barcelona districts or administrative subdivisions, and the sampling points.

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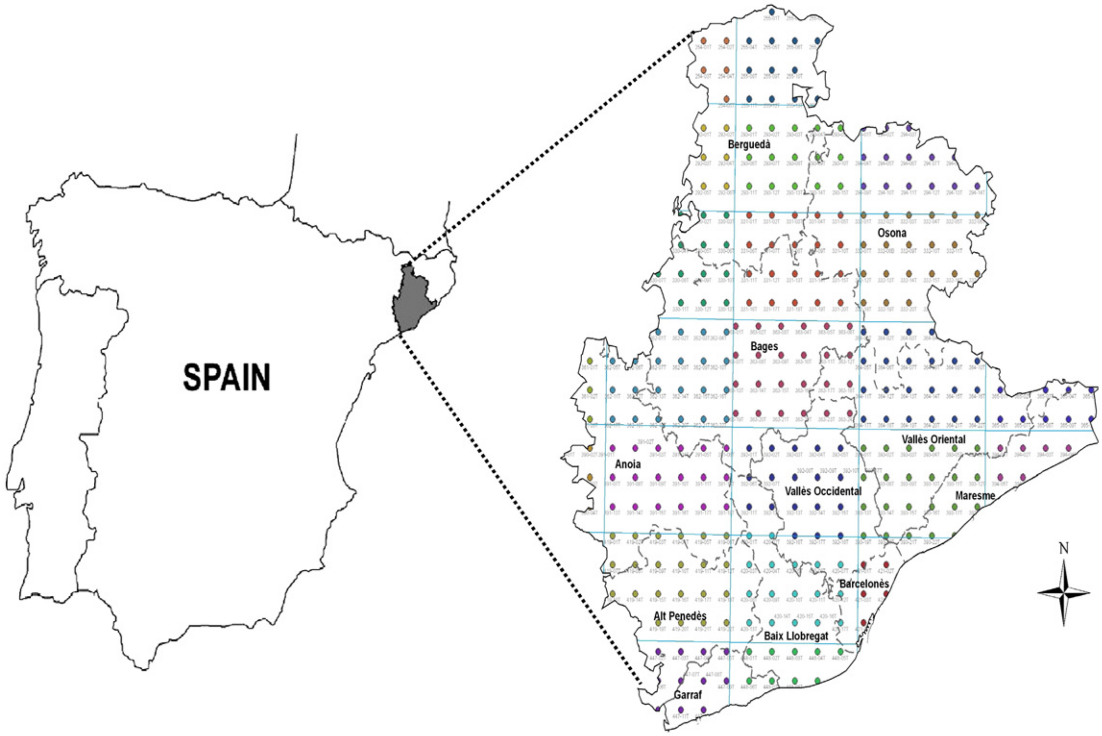

Fig. 1. Area of study showing the sampled points in Barcelona province in NE Spain, limits and names of the administrative districts, and sampling locations. Adapted from Bech et al. (2008b).

Barcelona province (NE Spain) is in the middle of the Autonomous Community of Catalonia, between 41°15′–42°20′ N and 5°4′–6°28′ E, and has an area of 7731 km^2. It is limited by Tarragona province to the south-west, Girona province to the north-east, Lleida province to the north-west, and the Mediterranean Sea to the east.

The geology and physiography of Barcelona province present a wide variety of features, with low terrain heights ranging from the sea level to above 2500 m in the northern mountains, and including the valley of the Llobregat river which flows from the north to the south, to the Mediterranean Sea. Six morphological units can be considered (Fig. 2), which listed from south to north are:

1) The Coastal plain, made up by alluvial deposits;
2) The Coastal Range, formed by mainly calcareous materials (SW of Llobregat river) and by siliceous rocks (granite and schists, to the NE);
3) The Pre-Littoral Depression, with Miocenic and Pliocenic limestones, arkoses, and lutites (maximum heights about 200 m asl);
4) The Pre-Littoral Range (maximum heights approximately 1700 m) formed, to the SW of the Llobregat fault by conglomerates, sandstones, and limestones, and, to the NE, by granites;
5) The Central Depression Uplands (with heights about 400 m), made up by Eocene and Oligocene sandstones, lutites and limestones; and
6) The Pre-Pyrenees range, with maximum heights reaching about 2500 m, formed mainly by limestones of the Late Cretaceous.

In the region of study there are four main soil groups: Leptosols, Cambisols, Fluvisols and Luvisols; an overview can be found in Jones et al. (2005). On the other hand, there is a wide variety of vegetation, ranging from holm to oak wood—which is predominant in the province—(among others *Pinus halepensis*, *Pinus pinea*, *Quercetum ilicis galloprovinciale* and *Quercus ilex*), boreal pine vegetation in the northern highest part (*Pinus mugo*, *Abies alba*, etc.), eurosiberian mixed woods in the shaded hillsides and medium height zone of the northern ranges (*Fagus sylvatica*, *Pinus sylvestris* and *Quercus pubescens*), and, over limestones, *Buxus sempervirens*.

General climatic conditions of Barcelona province belong to the warm temperate Köppen–Geiger types, exhibiting a north to south transition from *Cfb* to *Csa* (Kottek et al., 2006). The *Cfb* type in the north consists of fully humid and warm summers, whereas the *Csa* presents dry and hot summers. Local climatic features are mainly modulated by terrain height and continentality—see Clavero et al. (1996) for more details. Yearly average daily temperatures range from

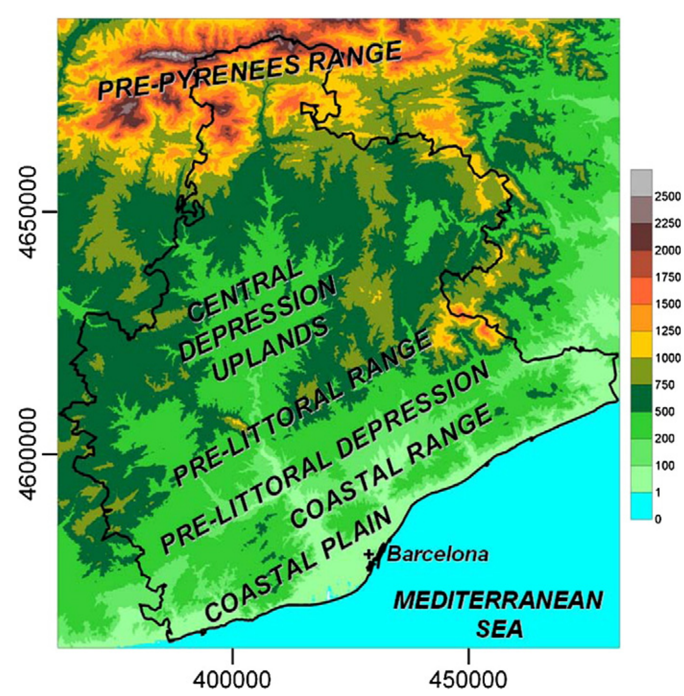

Fig. 2. Topographical map of Barcelona province, showing the main morphological units and also the location of the city of Barcelona. Heights are given in m and reference labels of the north–south and east–west axes are in km (UTM Cartesian projection).