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Using multivariate analyses and GIS to identify pollutants and their spatial patterns in urban soils in Galway, Ireland

Chaosheng Zhang*

Department of Geography, National University of Ireland, Galway, Ireland

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Multivariate statistics and GIS are useful tools to identify pollutants in urban soils.

Abstract

Galway is a small but rapidly growing tourism city in western Ireland. To evaluate its environmental quality, a total of 166 surface soil samples (0–10 cm depth) were collected from parks and grasslands at the density of 1 sample per 0.25 km^2 at the end of 2004. All samples were analysed using ICP-AES for the near-total concentrations of 26 chemical elements. Multivariate statistics and GIS techniques were applied to classify the elements and to identify elements influenced by human activities. Cluster analysis (CA) and principal component analysis (PCA) classified the elements into two groups: the first group predominantly derived from natural sources, the second being influenced by human activities. GIS mapping is a powerful tool in identifying the possible sources of pollutants. Relatively high concentrations of Cu, Pb and Zn were found in the city centre, old residential areas, and along major traffic routes, showing significant effects of traffic pollution. The element As is enriched in soils of the old built-up areas, which can be attributed to coal and peat combustion for home heating. Such significant spatial patterns of pollutants displayed by urban soils may imply potential health threat to residents of the contaminated areas of the city.

Keywords: Multivariate statistics; GIS; Urban geochemistry; Traffic pollution; Heavy metals

1. Introduction

Ireland is traditionally an agricultural country, which has been regarded as a green island with little industrial pollution, except in the vicinity of mining sites such as Silvermines (McGrath et al., 2004) and big cities. With the economic boom of the "celtic tiger" in recent years, traffic pollution has become the primary air pollution source in Ireland (EPA, 2004). However, little research has been carried out on its influences on the environment, including urban soils.

Urban soils are recipients of various pollutants that can be accumulated over a long time. Studies of urban soils started in the 1960s and heavy metal pollution was identified (Purves, 1966). Elevated concentrations of heavy metals, especially Pb, were found in urban and garden soils (Wilkins, 1978; Davies, 1978) due to use of leaded petrol. There are various pollution sources (Fuge, 2005) including vehicle exhausts (Page and Ganje, 1970; Harrison et al., 1981; Ho and Tai, 1988), waste incineration (Schuhmacher et al., 1997), metalliferous industries of mining, smelting and manufacturing (Thornton, 1991), airborne dust (Simonson, 1995), road abrasion and building materials, etc., among which traffic is the major pollution source in urban areas where there are no significant industrial or mining activities. Besides vehicle exhausts, recent studies have revealed that heavy metals in urban soils also come from wear-and-tear of tires and brakes (Sadiq et al., 1989; Smolders and Degryse, 2002; Adachia and Tainoshob, 2004). Owing to environmental and health concerns, heavy metals in urban soils have been studied in many big cities such as Glasgow (Farmer and Lyon, 1977), London (Kelly et al., 1996), Hong Kong (Li et al., 2001; 2004), New Orleans (Mielke et al., 2000) and Oslo (Tijhuis et al., 2002). A recent study on a small town in Finland (Peltola and Åström, 2003) showed enriched concentrations of heavy metals in urban soils.

* Fax: +353 91 495505.
E-mail address: chaosheng.zhang@nuigalway.ie

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In studies of heavy metal pollution in urban soils, different researchers have chosen different elements for study. One way to choose the elements that are typical or major pollutants in a specific area is based on experience or previous knowledge. When multiple elements are measured via inductively coupled plasma-atomic emission spectrometry (ICP-AES), there is an opportunity to perform multivariate analyses, and to identify the major pollutants in an objective way. This is a challenge when both the pollution sources and pollution levels are unknown previously. Recent studies have attempted to apply both multivariate analyses and GIS techniques in urban soil studies (Facchinelli et al., 2001; Manta et al., 2002; Li et al., 2004).

In urban areas, natural soils have been heavily disturbed by human activities, and in parks soils are generally imported from elsewhere. This has created difficulties in studying the natural conditions of soil geochemistry. One way of identifying pollutants from human sources is to compare the values with the averages of the Earth's crust or some background values. However, as Reimann and de Caritat (2005) pointed out such comparisons do not necessarily provide information on pollution. Pollution can only be regarded as one of many possible factors that can cause high element concentrations in soils. Several natural factors will also enrich a multitude of elements in topsoils. Heavy metals and many other elements exist in the environment in different forms and in different minerals. They may exhibit some form of multivariate relationships and spatial patterns. If significant spatial patterns can be related to human activities, it may be possible to identify the pollutants. Therefore, three criteria can be considered to identify pollutants: (1) relatively high concentrations; (2) different multivariate relationships from elements of natural origins; (3) spatial patterns related to pollution sources.

Previous studies on urban soils mainly focused on big cities, and Galway is a small city located in western Ireland, which makes it an interesting topic to study. The objectives of this study were to investigate the current state of environmental quality in soils of the study area, and to identify possible pollutants, their spatial patterns and possible pollution sources using multivariate analyses and GIS mapping techniques.

2. Methods

2.1. Study area

Galway is located on the western coast of Ireland, and is a popular tourism destination. Even though the environmental quality is generally regarded as in a good state, urban sprawl is taking place rapidly in recent years. The population in Galway city increased 15% from 57,241 in 1996 to 65,832 in 2002 (CSO, 2003). With the student population, the number of residents in Galway city is estimated at about 80,000. In 2003, a total of 951,000 overseas tourists visited Galway city or county (Fáilte Ireland, 2004). For the sustainable development of such a traditional city, it is necessary to understand the state of its environmental quality. Specifically, we need to know if there is environmental pollution and what are the pollution sources. In Galway city, there are no known significant rock mineralization or industrial pollution sources. The bedrock types are limestone in the east and granite in the west (Fig. 1), both having fairly low concentrations of heavy metals.

The study area extends 9 km E–W and 6 km N–S. This was chosen based on the 2nd edition of Galway Street Map of Ordnance Survey of Ireland (OSI), excluding 1 km in the west and 1.5 km in the east that are mainly rural areas (Fig. 1 and 2). In all maps in this study, the 500 × 500 m grid system of the Galway Street Map is adopted for easy reference of geographical locations. The digital elevation model (DEM) at the resolution of 10 × 10 m for Galway city was acquired from OSI (Fig. 2). The city centre of Galway is located at the mouth of River Corrib, with DEM values of 5–10 m above sea level. The highest area is located in the NW part, with an elevation of about 100 m.

Natural soil type in the study area is mainly grey brown podzols. In the granite area, there are small areas of lithosol with poorly developed soils. The average annual rainfall is about 1200 mm.

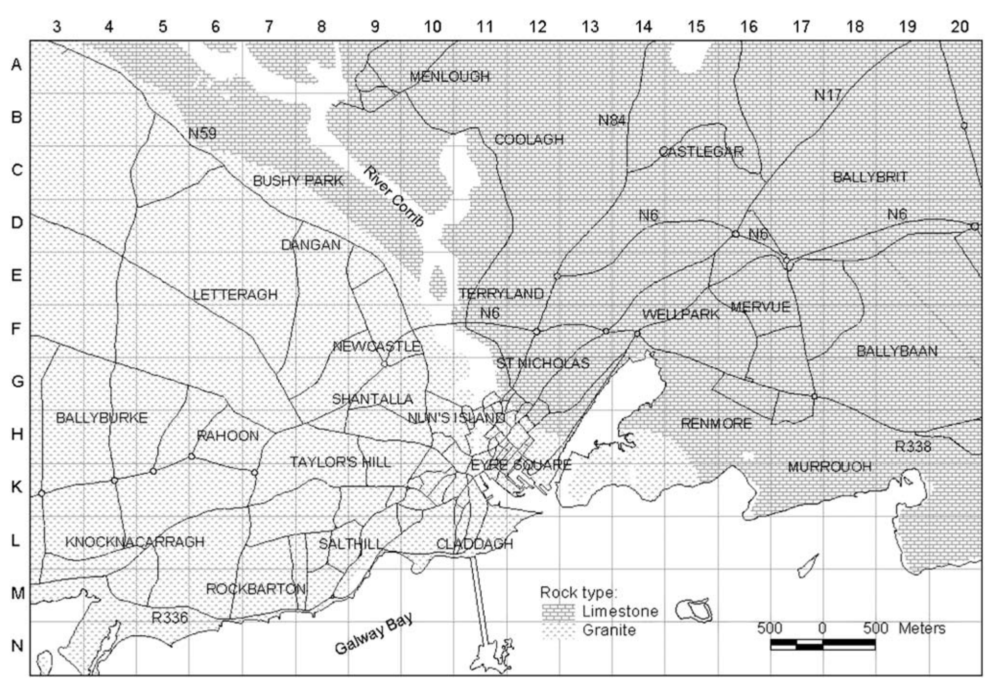

Fig. 1. Simplified geology map of Galway city.