Applied Geochemistry xxx (2017) 1–8

Contents lists available at ScienceDirect

Applied Geochemistry

journal homepage: www.elsevier.com/locate/apgeochem

Spatial distribution patterns of phosphorus in top-soils of Greater London Authority area and their natural and anthropogenic factors

Yuting Meng [a], Mark Cave [b], Chaosheng Zhang [a, *]

[a] *International Network for Environment and Health, School of Geography and Archaeology, National University of Ireland, Galway, Ireland*
[b] *British Geological Survey, Environmental Science Centre, Nottingham, United Kingdom*

ARTICLE INFO

Article history:
Received 8 January 2017
Received in revised form
30 May 2017
Accepted 31 May 2017
Available online xxx

Keywords:
London
Phosphorus (P)
GIS
Local Moran's I
Urbanization
The Thames Estuary
Parent materials (PMs)

ABSTRACT

Soil phosphorus (P) has a strong impact on soil and water quality. Soils in urban areas tend to enrich P, however, they have not been adequately investigated. A total of 6467 top-soil samples were collected and analysed by the British Geological Survey, providing basic data for studying the top-soil P distribution patterns and their environmental implications. The hotspots and cool spots were identified using the index of local Moran's I, which is a powerful methodology for discerning spatial clusters and spatial outliers. Combined with the results of one-way analysis of variances (ANOVA), a strong natural control of P was illustrated with elevated concentrations in areas of alluvium and river terrace deposits. P concentration in the lower Thames Estuary was clearly influenced by the tidal effect which has diluted the P-enriched sediments. The high concentration of Si and low pH level were linked to the low value clusters of P in Hyde Park and Richmond Park. Besides the natural control, the high value clusters concentrated in the city centre and built-up area, which indicated soil P content was strongly affected by human activities. The results of a *t*-test also showed the significant distinction of P concentrations between urban area and non-urbanised area, implying that urbanization and built-up materials accounted mostly for the locations and magnitude of the P pool. To conclude, the spatial patterns of P observed in the study area were controlled by both natural (parent materials (PMs) and geomorphology) and anthropogenic (urbanization) factors.

1. Introduction

With the worldwide rapid urbanization, urban soils are receiving considerable attention due to their associations with the life quality of human beings (Norra and Stüben, 2003). Phosphorus (P), as a limiting nutrient for organisms, is responsible for water eutrophication (Conley et al., 2009; Halecki and Gąsiorek, 2015). The P-enriched urban soils can affect groundwater quality via leaching (Zhang et al., 2001). Moreover, P derived from urban household waste can decrease the stability of organic carbon (C) in urban soils, resulting in organic C loss (Chen et al., 2014). Therefore, the locations and scale of soil P accumulation provides crucial information for P management, in particular preventing P leaching into water bodies.

Previous researches have revealed that P enriched in the soils of a number of big cities, including Nanjing (Zhang et al., 2001), Hangzhou (Zhang, 2004), Beijing (Xia et al., 2013), Nanchang (Chen et al., 2014) of China, Bangkok (Faerage et al., 2001) of Thailand, Gälve (Nilsson, 1995) of Sweden and Phoenix (Metson et al., 2012) of the USA. There are a number of factors influencing P accumulation and sequestration in urban areas, such as parent materials (PMs), hydrology, biotic processes, and current and historical land use and management (Bennett, 2003; Bennett et al., 2004). These factors can be classified into two categories: the natural (internal) factors and the anthropogenic (external) factors. The natural source of P comes from PM which plays a role in driving differences in P status in long-timescale (Mage and Porder, 2013). Appleton et al. (2013) reported that PMs control 12–16% of the variance of P in the London region. The external sources of P are composed of fertilizer application for agricultural purpose in fields and green spaces, food and human waste, building materials like asphalt, wood and cement (Metson et al., 2012), among which sewage treatment works and septic tanks are two main inputs of P to urban soils (Neal et al., 2005). The phenomenon of P accumulation in surface soils implies that human activities can modify P concentration to some extent. Interestingly, P has long been used to

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* Corresponding author.
E-mail address: Chaosheng.Zhang@nuigalway.ie (C. Zhang).

http://dx.doi.org/10.1016/j.apgeochem.2017.05.024
0883-2927/© 2017 Published by Elsevier Ltd.

Please cite this article in press as: Meng, Y., et al., Spatial distribution patterns of phosphorus in top-soils of Greater London Authority area and their natural and anthropogenic factors, Applied Geochemistry (2017), http://dx.doi.org/10.1016/j.apgeochem.2017.05.024

indicate human activities in the field of archaeology during pre-agricultural and agricultural ages (Holliday and Gartner, 2007).

The study area, London, is the capital of the United Kingdom with a two-thousand-year history as a major settlement. The population was 8.2 million based on the 2011 Census and will continue to increase in the next few decades (Great London Authority, 2016). The land use and soil quality could be changed dramatically in suburban areas. The local government makes efforts to upgrade sewage (including sludge) treatment capacity and develop the Thames Tideway Sewer Tunnels in order to address the issues of sewer overflows and improve the water quality (Great London Authority, 2016). Consequently, to reduce economic cost and increase the efficiency of controlling P contamination, the hotspots which pose a potentially high risk should be targeted critically and the input sources should be assessed (Huang et al., 2012).

When considering a mixture of natural and anthropogenic controls, geographical information system (GIS) and spatial analyses, for example, inverse distance weighted (IDW) interpolation and local Moran's I, are powerful tools to explore P spatial distribution and identify of hotspots and cool spots. Hotspots are the area with high values of P concentration, oppositely, cool spots represent the area with low values. The local Moran's I, one of Local Indicators of Spatial Association (or Autocorrelation) (LISA) methods, has been widely used for extraction of spatial patterns (Bone et al., 2013; Voutchkova et al., 2014; Majumdar and Biswas, 2016). In terms of soil contamination researches, hotspots often represent contamination sites in comparison to the values of their neighbours (Zhang et al., 2008).

In this study, the GIS mapping techniques and spatial analyses are implemented to address the issues as follow: i) to reveal the spatial patterns of P in top-soils of the Greater London Authority (GLA) area; ii) to identify the locations of P accumulation and depletion; and iii) to explore the natural and anthropogenic factors causing the spatial patterns.

2. Materials and methods

2.1. Soil parent material

A surface PM map (Fig. 1) with simplified geological types (Miles and Appleton, 2005) was adopted for the study. Cretaceous and Palaeogene bedrocks cover the most of the GLA area, meanwhile some parts of the area are underlain by substantial Quaternary superficial deposits (British Geological Survey, 2011). The white chalk subgroup, formed in the Cretaceous, is the oldest bedrock within the GLA area, while the Thanet sand formation is the oldest Palaeogene deposit. The Lambeth group, Thames group, and Bracklesham group belong to Palaeogene deposits, cropping out extensively, among which Thames group is the most widespread. The Quaternary deposits include clay-with-flints, glacial till, river terrace deposits, alluvium, and Head. The clay-with-flints formed from the original Palaeogene cover, and earlier Quaternary deposits are heterogeneous in texture, colour, and clast content. Glacial till is deposited by the Anglian ice sheet which comprises mostly of stiff pebbles or boulders and silty clay. River terrace deposits have been formed by the diversion of the River Thames, and the gravel deposition crops out mainly on hilltops. Alluvial deposits that primarily form a flat surface in valleys of the rivers Thames and Lee are most recent deposits within the research area. Generally, the alluvium consists principally of silty clay and fine-to coarse-grained sands.

2.2. Soil chemistry data

In the GLA area, a hand-held auger was used to collect 6467 top-soil samples by British Geology Survey. The sampling density was 4 samples per square kilometre and the sampling depth was ca. 5–20 cm. At each site, a composite sample based on 5 sub-samples was taken at the centre and four corners of a 20 m square. Soil samples were air-dried and sieved through a nylon sieve with 2 mm apertures. Coarse powder were sealed into vessels containing mill balls after simply disaggregated by hand in a pestle and mortar. Milled powder was compressed into pellets with the addition of solid binder which was used to improve adhesion of urban samples (Johnson, 2011). Forty-eight trace and major chemical elements were measured by X-ray fluorescence (XRF) spectrometry. Besides, loss on ignition (LOI at 450 °C) and pH were also determined. Details of sample preparation, analytical methods, and quality control procedures were described in Allen et al. (2011) and Johnson (2011).

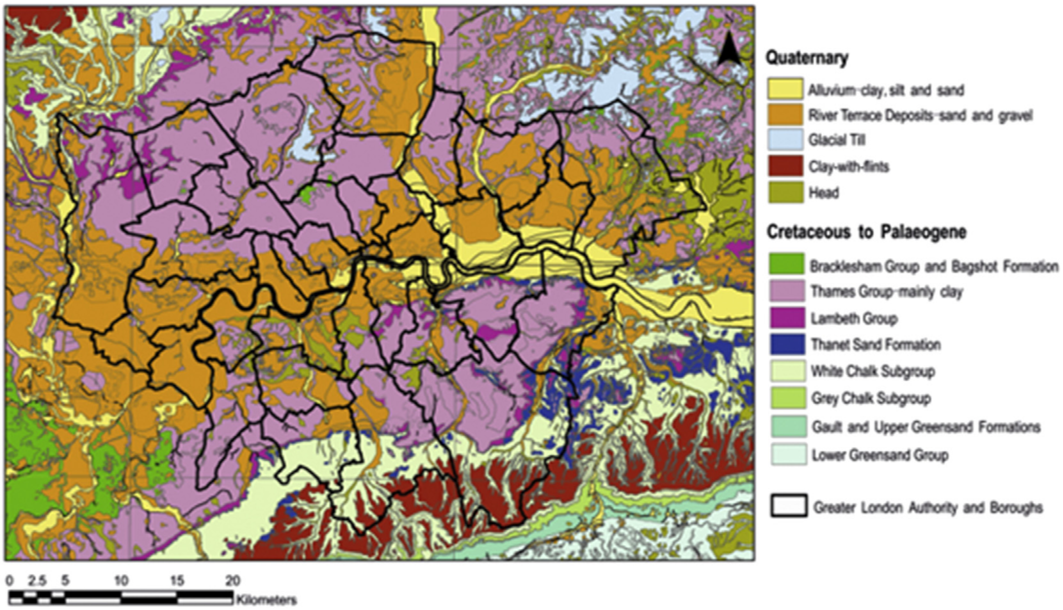

Fig. 1. Geology map of the London region.

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