London Atlas: Preliminary conclusion

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Ferreira, A, Johnson, C C, Appleton, J D, Flight, D M A, Lister, T R, Knights, K V, Ander, L, Scheib, C, Scheib, A, Cave, M, Wragg, J, Fordyce, F and Lawley, R. 2017. London Region Atlas of Topsoil Geochemistry. *British Geological Survey*.

The geochemistry of soil is dependent on several factors, principally the bedrock geology and/or superficial deposits from which they are derived. Other spatially and temporally varying factors, such as climate, land use and topography, are crucial in the development and shaping of the soil itself. Soil is a complex and evolving entity consisting of a mixture of minerals, organic matter, living organisms, water and air, with the depth extension and composition varying from place to place. The mineral component is frequently composed of weathered rock and mineral fragments, and different clay minerals, Fe, Mn and Al oxides and hydroxides, secondary carbonates and sulphates, all derived from the materials under weathering. Organic matter originates from living organism, namely plants and soil biota, decay. Water and air are mainly obtained from the atmosphere, but also from chemical, physical and microbial reactions permanently taking place. Soil also contains pollutants derived from anthropogenic activity such as urbanisation, energy generation, transportation, waste disposal, agriculture, mining and industry. This and further information about soil structure and composition can be found in FitzPatrick, 1986[1], White, 2006[2], Kabata-Pendias, 2011[3].

A previously published BGS G-BASE[4] project, London Earth[5], was carried out to provide insight into the environmental impacts of urbanisation and industrialisation on land quality as well as to characterise the soil geochemical baseline of the Greater London Authority area. Detailed descriptions of the controls on soil chemistry for selected elements within the London Earth area have been described previously (London Earth[5], Knights and Scheib, 2011[6]; Scheib et al., 2011[7] and Appleton et al., 2013[8]). Scheib et al. (2011)[9], when referring to evidence of anthropogenic modification to soil baseline concentrations, point to the higher concentrations of, for example, Pb, Sb, CaO, Zn, Cu, Sn and As in the oldest, most intensely urbanised parts of the city; as well as to several Se, Cd, Ni, Cu and Zn 'hot spots' in the vicinity of an industrial area on the banks of the River Lee in north London and to the high concentrations of Cr and Cd around Heathrow airport in the west. Patterns of other elements, are referred as being strongly related to the geology, namely the high contents of CaO, Ce, I, La, MnO, Nd, P_2O_5, Sr and Y over Cretaceous chalk bedrock, the high contents of Al_2O_3, Fe_2O_3, MgO, K_2O, Cr, La, TiO_2, Ga, Rb and Ni over Palaeogene clays, or elevated contents of Hf and Zr over Eocene marine and Quaternary wind-blown deposits. Another interesting feature also pointed out by Knights and Scheib, 2011[6], is the consistently low concentrations of As, CaO, Cr, Cu, Fe_2O_3, Ni, Pb and Zn associated with four park areas in south-west London, which contrast with surrounding areas. The relation between Pb concentration and land use classes is further studied by Lark and Scheib (2013)[10] inside the Greater London Authority area; the authors observe that the land use is an important source of variation in lead content of topsoil, with the largest mean lead content observed on the industrial sites followed by domestic gardens, contrary to, for example, parks and recreational areas; these authors suggest that the high Pb content in domestic gardens is most likely related with two historical factors: burning of domestic waste and spreading of ash (no longer a practice) and the use of lead-based paints (banned since 1992). Mao et al. (2014)[11], after analysing Pb isotopic ratios (206Pb/207Pb and 208Pb/207Pb) in soil samples from three land use types, namely, land adjacent to a major rural road, from a sewage processing farm and from London, concluded that the total Pb in soil, including that from London, falls on a mixing line between those of petrol and UK coal or Pb ore; these autors further concluded that soil pH is the main determinant of the isotopically exchangeable Pb fraction in soil, with exchangeable Pb decreasing with increasing pH. Appleton et al. (2013)[12], after an analysis of variance (ANOVA), suggest that the geochemical patterns of Cd, As, Ba, Cr, Cu, Mo, P_2O_5, Pb, Sb, Se, Sn and Zn in topsoils of the London area are poorly dependent on the underlying geology, thus most likely influenced by anthropogenic factors; and that, for most of these same elements, the geochemical patterns are generally less dependent on the underlying geology in urban domain compared with the rural domain. On the contrary, the patterns of Al_2O_3, Ce, Cs, Ga, K_2O, La, MgO, MnO, Nb, Nd, Rb, TiO_2, V and Y closely associate to the underlying geology, and, for most of these elements, the geochemical patterns related to underlying geology are equally detectable in rural and urban domains. Patterns of CaO, Co, Fe_2O_3, I, Ni, Sc, Sr and Th show an intermediate behaviour relative to the previous groups of elements.

The link between soil geochemistry and the underlying geology, including in urban areas, led to the development of a geochemical mapping method using parent material classified data (Appleton and Adlam, 2012[13]). This same geochemical mapping method has been used for the production of this present atlas (see Data visualisation for further explanation).

The London Region Atlas of Topsoil Geochemistry presented here, was developed by joining the topsoil geochemical data from the London Earth project with other G-BASE topsoil geochemical data from rural locations in south-eastern England (SEEN). This provided a framework to investigate and compare the soil geochemical signature of the urbanised Greater London Authority area with that of the surrounding peri-urban / rural area, thus allowing for a better understanding of the environmental impacts of urbanisation and industrialisation of London on soil quality.

Comparisons of compositional mean values show that soils in central London contain more than double the amount of Pb, Sb, Sn, Cu and Zn than rural soils (**LOND**/**SEEN** ratio > 2, Log(**LOND**/**SEEN**) > 0.3, **Table 10**). This enrichment pattern applies to the 13 parent materials for which is possible to compare **LOND** and **SEEN** (**Table 7**), as can be observed in the respective graphics of **LOND** and **SEEN** topsoil concentrations over each geological unit. Similarly, the urban soils are enriched in Mo, Ge and CaO (**LOND**/**SEEN** ratio > 1.4, Log(**LOND**/**SEEN**) > 0.15, **Table 10**) and to a lesser extent Cd, P_2O_5, Se, As, Br, Bi and Ni (**LOND**/**SEEN** ratio > 1.2, Log(**LOND**/**SEEN**) > 0.08, **Table 10**) than rural soils. These parameters constitute a typical indicator suite of urban soil pollution reported in several other cities also (Fordyce et al., 2005[14]; Flight and Scheib, 2011[15]).

This reflects the strong anthropogenic fingerprint of London and its impact on land quality, as exemplified by the distribution of Pb in topsoil, which shows a bullseye pattern radiating out from higher values in the centre of London to background values in the surrounding rural environment over a distance of ca. 20 km. In the case of Pb, this probably reflects its former use in petrol and paint with dispersion into the soil environment greatest in areas of highest traffic and building density in the city centre. For the other elements, typical urban sources of pollution in soils include demolition and building rubble; burial of waste; presence of artificial ground; the historic dispersal of domestic and industrial coal ash into urban soils; fertiliser use; atmospheric deposition of pollutants; surface-water run-off; emissions and waste disposal from traffic, energy generation, waste disposal, industry and domestic sources (Johnson et al., 2011[16]).

The Br marginal enrichment observed in central London is perhaps the exception to the typical indicator suite of urban soil pollution referred above. The Br content of many soils is controlled by the deposition of marine aerosols, which are trapped in organic matter; hence its distribution is similar to that of LOI (an indicator of organic matter content) across London. The distribution of Br could also reflect the marine nature of the underlying parent materials of London soils. The salt-water influence on Br concentrations in soil in the Thames estuary is evident from the Br map also.

The observation of the graphics of **LOND** and **SEEN** topsoil concentrations over each geological unit, however, strongly suggests that the Br (and LOI) marginal enrichment in central London is independent of the parent material, and, thus, it is not likely to be explained by the geology alone. This contrasts with other cities of the UK. In most of the cities, LOI values are higher in the surrounding rural soils, reflecting their more natural composition and higher organic matter content, relative to the urban environment.

The general anthropogenic pattern observed for central London is possibly emphasised by the geographical characteristics of this area: a topographic low related with the tidal section of the River Thames walled by the north-west and south-east Chalk-related topographic highs, which may act as a trap where the surrounding geogenic and anthopogenic loadings converge.

By contrast to the enriched set of elements, parameters such as Hf, I, Zr, MnO, Cs and La are marginally lower on average (**LOND**/**SEEN** ratio < 0.9, Log(**LOND**/**SEEN**) < -0.05, **Table 10**) in urban than in rural soils demonstrating that the distributions of these elements are largely controlled by geological and soil-forming processes rather than anthropogenic pollution. Again, this is a typical indicator suite of geogenic signature elements found around other cities also (Fordyce et al., 2005[14]; Flight and Scheib, 2011[15]). The depression observed in the central London in the distribution of these elements (e.g.: Hf) do not necessarily mean that these elements have been *removed* from the central London soils. Instead, this is, most likely, a direct consequence of the *excess* loading of anthropogenic elements (e.g. Pb). Thus the depression is rather an effect of the compositional nature of the dataset. In fact, if a soil has 100 units of a geogenic pristine composition A, to which is *added* 100 units of an anthropogenic composition B, the measured values will be 50 of A and 50 of B. The geogenic component will look like depressed (A = 50%) relative to another pristine soil having 100 units of the same geogenic composition A only (A = 100%).

In summary, the process of urbanisation has had a significant impact on topsoil quality within the London region. Chemical elements that are typically found in very low concentration in most natural soil such as Pb, Sn, Sb, Cu, Zn are on average up to three times higher in urban than in rural soils as a result of pollution from anthropogenic activities.

This atlas provides comprehensive information on the chemical quality of soils across the London region, contributing to an understanding of the sources and pathways of pollutants in the environment to aid sustainable land use planning and urban management in the future.

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