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Spatial patterns of trace element distributions in urban soils - a challenge for geo-statistical mapping, source identification and the determination of baseline levels

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Urban soils are a major sink for pollutants in urban systems, which are highly complex and comprise manifold pollution sources from the industrial, infrastructural and domestic sector. Some sources locally pollute soils, other sources contribute to the diffuse pollution of soils affecting expanded urban areas. Thus, the pollution patterns of soils vary across the urban area according to dominating land uses. Frequently occurring neutral conditions (pH around 6 to 7) in urban soils limit the mobility of many trace elements. Consequently, a creeping increase of trace element concentrations can be stated for many urban soils and large urban areas. This creeping pollution necessitates comprehensive monitoring and assessment of ongoing urban soil pollution. Although the chemical composition of urban soils is highly variable, we demonstrate by means of soil surveys, which we carried out in Karlsruhe-Mühlburg, Karlsruhe, Pforzheim, all Germany, and Qingdao, China, assessments of spatial relationships of the chemical composition of urban soils. We show that geo-statistical mapping of trace element concentrations in urban soils is a strong tool to investigate and visualize the spatial patterns of urban soil pollution. Experimental semi-variograms provide valuable information on the structures of spatial distributions of trace element concentrations in urban soils. In urban systems these experimental semi-variograms reflect superimposing urban land use structures responsible for soil pollution and the original chemical composition of soils. Kriging, based on fitted adequate models to experimental semi-variograms, enables the spatial interpolation of trace elements in urban areas. According to their land use structure, cities show specific patterns of the spatial distributions of diffuse soil pollution. This diffuse soil pollution covers large

areas and is a kind of a baseline level of overall anthropogenic soil pollution of urban soils. Geo-statistical methods are appropriate to investigate these specific patterns of diffuse pollution. Cross validation is a strong tool to detect outliers not fitting in the overall spatial model of diffuse soil pollution. In urban systems, these outliers can be soils heavily polluted by local pollution sources or soils consisting of allochthonous material locally admixed to the ground. The distinction between local and diffuse soil pollution at specific sites is a necessary task for the respective urban environmental management. Especially in cases of excesses of legal limiting values of soil pollution it has to be determined whether the pollution is caused by a local source or caused by the overall diffuse pollution. Beside that, elimination of such soil sites from the data set enhances the spatial correlation of trace element concentrations.

Multivariate statistical methods such as cluster and principal component analyses are appropriate methods to identify the main sources of trace elements in urban soils. These statistical methods produce reasonable results with respect to the identification of the impact of the parent material's chemical composition on the chemical composition of urban soils. Furthermore, soils intensively polluted by local sources can be identified and the impacts of various anthropogenic pollution sources such as traffic, power plants or metal processing can be distinguished. In many cases, urban areas stretch over more than one geological unit and the corresponding soil type. Therefore, natural baseline levels of trace element concentrations in soils vary across urban areas. This fact has to be taken into account when assessing the pollution levels of urban soils.

Conclusively, the assessment of such spatial relationships by means of geo-statistical and multivariate statistical methods provides valuable information for sustainable urban development. Each urban environmental management should be aware about the creeping diffuse pollution of the city's soils. The knowledge about spatial patterns of the chemical composition of urban soils is a precondition to identify, assess and mitigate urban soil pollution.