Science of the Total Environment 598 (2017) 938–948

Contents lists available at ScienceDirect

Science of the Total Environment

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

Trace element concentrations along a gradient of urban pressure in forest and lawn soils of the Paris region (France)

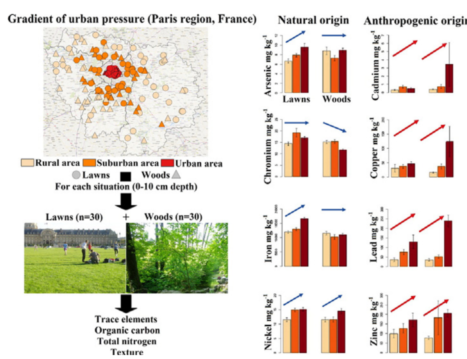
Ludovic Foti [a,b,*], Florence Dubs [a], Jacques Gignoux [a], Jean-Christophe Lata [a,c], Thomas Z. Lerch [a], Jérôme Mathieu [a], François Nold [d], Naoise Nunan [a], Xavier Raynaud [a], Luc Abbadie [a], Sébastien Barot [a]

[a] Sorbonne Universities, UPMC Univ. Paris 06, IRD, CNRS, INRA, UPEC, Univ Paris Diderot, Institute of Ecology and Environmental Sciences, iEES Paris, 4 place Jussieu, 75005 Paris, France
[b] NatureParif, 90-92B avenue du Général Leclerc, 93500 Pantin, France
[c] Department of Geoecology and Geochemistry, Institute of Natural Resources, Tomsk Polytechnic University, 30, Lenin Street, Tomsk 634050, Russia
[d] Laboratory of Agronomy of the Paris City, Paris Green Space and Environmental Division (DEVE), Parc Floral - Pavillon 5 - Rond Point de la Pyramide, 75012 Paris, France

HIGHLIGHTS

- The anthropogenic trace elements are cadmium, copper, lead and zinc.
- The anthropogenic concentrations increase from the rural to the urban area.
- The first source of pollution for anthropogenic trace elements is the road traffic.
- Cement plants are the second source of cadmium.
- The trace element pollutions are impacted by the legacy of the soil history.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 17 February 2017
Received in revised form 13 April 2017
Accepted 14 April 2017
Available online xxxx

Editor: F.M. Tack

Keywords:
Trace elements
Urban-rural gradient
Soils
Green spaces
Lawns
Forests

ABSTRACT

The concentration, degree of contamination and pollution of 7 trace elements (TEs) along an urban pressure gradient were measured in 180 lawn and wood soils of the Paris region (France). Iron (Fe), a major element, was used as reference element. Copper (Cu), cadmium (Cd), lead (Pb) and zinc (Zn) were of anthropogenic origin, while arsenic (As), chromium (Cr) and nickel (Ni) were of natural origin. Road traffic was identified as the main source of anthropogenic TEs. In addition, the industrial activity of the Paris region, especially cement plants, was identified as secondary source of Cd. Soil characteristics (such as texture, organic carbon (OC) and total nitrogen (tot N) contents) tell the story of the soil origins and legacies along the urban pressure gradient and often can explain TE concentrations. The history of the land-use types was identified as a factor that allowed understanding the contamination and pollution by TEs. Urban wood soils were found to be more contaminated and polluted than urban lawns, probably because woods are much older than lawns and because of the legacy of the historical management of soils in the Paris region (Haussmann period). Lawn soils are similar to the fertile agricultural soils and relatively recently (mostly from the 1950s onwards) imported from the surrounding of Paris, so that they may be less influenced by urban conditions in terms of TE concentrations. Urban wood soils are heavily

* Corresponding author at: Sorbonne Universities, UPMC Univ. Paris 06, IRD, CNRS, INRA, UPEC, Univ Paris Diderot, Institute of Ecology and Environmental Sciences, iEES Paris, 4 place Jussieu, 75005 Paris, France.
E-mail address: ludovic.foti@etu.upmc.fr (L. Foti).

http://dx.doi.org/10.1016/j.scitotenv.2017.04.111

polluted by Cd, posing a high risk to the biological communities. The concentration of anthropogenic TEs increased from the rural to the urban areas, and the concentrations of most anthropogenic TEs in urban areas were equivalent to or above the regulatory reference values, raising the question of longer-term monitoring.

1. Introduction

Urban soils differ greatly from natural soils because they are located in areas of intense human activity, resulting in more pollution, physical disturbance and surface transformation. Whole soil profiles are often man-made, sometimes with fertile agricultural soils from rural areas (Bullock and Gregory, 1991; Beaudet-Vidal et al., 1998). Urban soils are responsible for a number of ecosystem services, including the recycling of organic matter and mineral nutrients and plant growth, and contribute to the ecosystem services provided by urban green spaces (from the mitigation of urban heat islands to recreational services) (Stroganova et al., 1997; Chiesura, 2004). Due to the potential impact urban soils can have on urban populations, there has been an increase in interest in urban soils in recent years (Wong et al., 2006; Morel and Heinrich, 2008; Vegter, 2007).

Urban soils can be polluted because they receive a variety of deposits from both proximal (vehicle emissions, domestic heating, waste incineration) and more distal (through atmospheric transport) sources (Islam et al., 2015). Trace elements (TEs) are persistent in the environment, tend to bioaccumulate in the food chain and, at high concentrations, can be toxic for humans and other organisms (Dudka and Miller, 1999; Raghunath et al., 1999; Adriano, 2001). When TEs accumulate in the soil, they impact the activities of soil organisms (microorganisms, microfauna, macrofauna), alter food web functioning, reduce the organic matter decomposition rate and disrupt biogeochemical cycling (Bååth, 1989; Alloway, 2013).

Some studies have documented urban soil TE pollution and its distribution at the scale of towns or their surrounding regions (Yesilonis et al., 2008; Amuno, 2013). In France, several monitoring programs (*e.g.* National Network for Long-term FOrest ECOsystem Monitoring (RENECOFOR), national soil quality monitoring network (RMQS) and studies have been carried out at a national scale, in order to measure the ranges of French soil TE concentrations and to estimate their natural background values in the country. While these studies brought significant information on French agricultural and forest soils (Baize and Sterckeman, 2001; Hernandez et al., 2003), only a few authors focused on urban soils (Joimel et al., 2016; Vergnes et al., 2017). This study aims at filling this knowledge gap, focusing on contamination and pollution by these TEs in lawns and forests, as they constitute the main types of vegetation in urban public areas of the region. Contamination occurs when a substance has a concentration above its natural background concentration while pollution is a contamination that results in adverse biological effects (Chapman, 2012; ISO Soil quality, 2005). Consequently, the degree of TE pollution in a soil describes the potential risks for the biological communities living in this soil and on its surface (*e.g.* microorganisms, plants). Contamination was evaluated for each single TE using the contamination factor (CF) and for all soil TEs together using the overall degree of contamination (DC). Pollution was evaluated for each single TE by the potential ecological risk index (ER) and by the ecological risk (RI) index for the overall pollution by all TEs (Hakanson, 1980; Amuno, 2013; Islam et al., 2015).

The aims of the present study were (i) to examine the concentration of seven selected TEs (As, Cd, Cr, Cu, Ni, Pb, Zn) and one major element (Fe) in soils from two land-use types (public lawns and woods) along an urban pressure gradient in the Paris region, (ii) to identify the origin of the diffuse and/or point sources of contamination or pollution, (iii) to evaluate the individual and overall TE contamination degree as well as the individual and overall TE pollution degree, (iv) to use soil characteristics to better understand soil origins and histories along the urban pressure gradient and the relationship between these characteristics and TE concentrations. The TEs analyzed were chosen because their concentrations are known to be influenced by human activities, and because it do not exist for these TEs a real monitoring of their concentration over time, especially in the soil of the urban public green spaces of the region (Paris Green Space and Environmental Division, pers. comm.). Ultimately, this study contributes to establish baseline TE values for the long-term monitoring of the evolution of TE soil contents in urban areas of the Paris region.

2. Materials and methods

2.1. Study area

The Paris region is located in France (48°07′N, 1°35′E; 49°07′N, 3°26′E) and covers an area of 12,070km^2 around the city of Paris. The population is 12.01 million, representing approximately 18.8% of the total population of metropolitan France (INSEE – French National Institute of Statistics and Economic Studies, 2013). The region is subject to several sources of anthropogenic trace elements (*e.g.* waste incineration, road traffic, metal smelter industries, Natali et al., 2016). The topography, geology and hydrology are relatively even across the whole region. It is characterized by an average altitude of 108m and very low erosion rates (10tkm^{-2}yr^{-1}) owing to limited relief. The bedrock is exclusively sedimentary (Jurassic limestone and marl, cretaceous chalk, carbonaceous alluvial deposits, tertiary quartz sand). The climate is subatlantic with an average temperature of 11°C and a rainfall of 600mm per year. The rainfall regime is pluvial oceanic (Pomerol and Feugueur, 1968). The climate is regionally marked by an urban and suburban heat island phenomenon (Tremeac et al., 2012).

2.2. Determination of urban pressure gradient of the Paris region

The urban pressure gradient of the Paris region was described using two spatialized indices, a Socio-Demographic Index (SDI) and a Heat Island Index (HII). The SDI is an average human activity density index per hectare of surface built. This type of index is frequently used in urban planning and territorial development (Frenkel and Ashkenazi, 2008). It allows the identification of the areas of a region that are most frequented by the population and that concentrate employment. The SDI map was made by the Paris Region Planning and Development Agency (IAU Île-de-France), by summing the population density and the employment density of the region (data set 2014, provided by INSEE). The result was normalized using the total built surface (data set 2014, provided by IGN – French National Geographic Institute). The spatial resolution of the SDI map was 250×250m. The HII uses the values of the minimal temperature recording to identify the areas that are most affected by human activities and the overall degree of artificial land cover (*e.g.* tar roads, buildings). The HII was calculated as the average of the monthly minimum temperature from January 2013 to December 2015 (data provided by Météo France – French Institute of Meteorological Prevision). The spatial resolution of the HII map was 2×2km.

To build the urban pressure map, the SDI and HII data were combined using GIS software (ArcGIS v.10) to obtain one map with a resolution of 2×2km. This was achieved by averaging the SDI values with an 8×8 filter to obtain a resolution of 2×2km. The urban pressure gradient