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

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1 Introduction

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 TM concentrations and estimate their natural background values in the country. While these studies brought significant information on French agricultural and forest soils, they did not focus on urban soils. Consequently there is a lack of data regarding TM concentrations and subsequent risks in urban soils of France, especially in the Paris region (Île-de-France).

The aims of the study were (i) to examine the concentration of 8 selected TMs (As, Cd, Cr, Cu, Fe, Ni, Pb, Zn) in soils of 2 land-uses (public lawns, woods) along an urban pressure gradient in Paris region, **(ii)** to distinguish origin, and diffuse *vs.* point sources of contamination or pollution, **(iii)** to evaluate the individual and overall TM contamination degree as well as the individual and overall TM 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 TM concentrations. **(v)** Ultimately, this study contributes to establish baseline TM values for long-term monitoring of the evolution of TM soil contents in urban areas of Paris region.

2 Urban pressure gradient

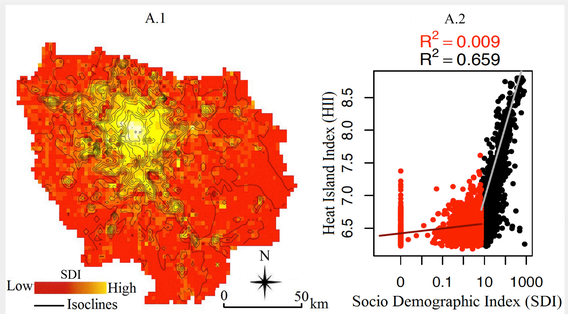
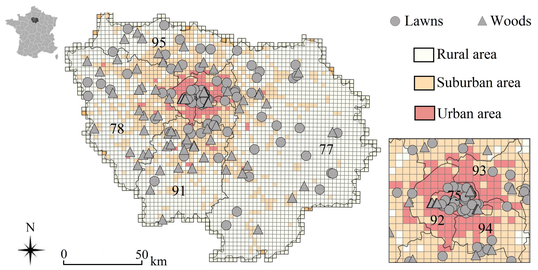


Figure A - (A.1) Map of correlation between the Heat Island Index (HII) and the Socio-Demographic Index (SDI), resulting (A.2) of the log-linear piecewise regression analysis of the SDI and HII datasets. Map isoclines match to T° ranges (5.0 to 8.5°C).

Three classes were considered in the analysis:

a rural class with HDI values independent from SDI values (< 10 inhabitant employment ha^{-1} and < 7.20°C, respectively),
a suburban class (10-100 inhabitant employment ha^{-1} and 7.20-8.00°C, respectively) and
an urban class (>100 inhabitant employment ha^{-1} and > 8°C, respectively) for which the HII increases with the SDI.

3 Sampling design *(n=180)*



For each situation (0-10 cm depth)

Lawns (n=30) + Woods (n=30)

Trace metals
Organic carbon
Total nitrogen
Texture

4 Soil sample analyzis

Texture (clay, silt, sand)	→	**NF X 31 - 107 standard**
Organic Carbon (OC)	→	**NF ISO 10694 standard**
Total Nitrogen (tot N)	→	**NF ISO 13878 standard**
Arsenic (As)	→	**NF ISO 20280 standard**
Iron (Fe)	→	**NF EN 13346 standard**
Cadmium (Cd) + Chromium (Cr) + Copper (Cu) + Nickel (Ni) + Lead (Pb) + Zinc (Zn)	→	**NF ISO 11466 standard**

5 Contamination / pollution

Contamination [1]
=
[TM] above natural background [TM]
↓
Each single TM
=
Contamination Factor (CF) [3]
+
All soil TMs together
=
Degree of Contamination (DC)

Pollution [1]
=
Contamination → 
↓
Each single TM
=
potential Ecological Risk index (ER) [3]
+
All soil TMs together
=
Ecological Risk (RI)

Iron (Fe) → *Reference element [2]*

6 Results and discussion

Physico-chemical soil characteristics

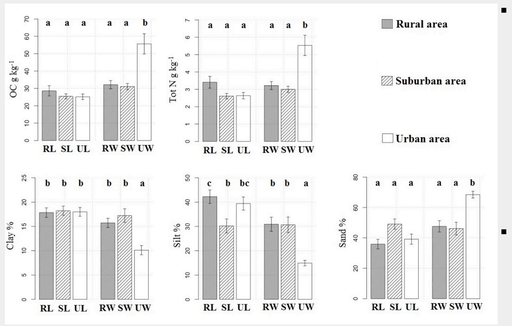


Figure 1 - Mean values (with SE) of physico-chemical soil characteristics in lawns and woods from rural, suburban and urban areas of Paris region. (OC: *Organic carbon*, tot N: *total Nitrogen*, Clay, Silt and Sand). RL: rural lawns, SL: suburban lawns, UL: urban lawns, RW: rural woods, SW: suburban woods, UW: urban woods. Letters indicate significant differences between means.

- **Lawn soils:** Similar physico-chemical soil characteristics along urban pressure gradient **= Lawn soils could all have the same origin:**
  - Ages of creation of urban and suburban public green spaces hosting the sampled lawns relatively recent (1970 to 2011),
  - Characteristics of the lawn soils (*e.g.* texture) do correspond to the properties of soils of croplands of the Paris region.
  - Since 1950, arable lands have been artificialized in Paris conurbation area where Paris and its suburbs were expanding → Fertile soils of these lands excavated **+** resold as substrate for public green spaces of Paris conurbation.
- **Wood soils:** Different physico-chemical characteristics along urban pressure gradient **= Urban soil woods not of the same origin:**
  - Created under the **historical period of Haussmann's renovation of Paris (1853 to 1867)**,
  - From market garden soils already rich in organic materials **+** fertilized with wastewater as irrigation source in large quantities, beginning at Haussmann period until 1950.
  - Physico-chemical characteristics **+** ages of creation strongly suggest historical legacy of the Paris city restructuration → Urban public green spaces profoundly recast or created → Market urban garden lands **+** Recreation areas for urban Paris population.
- **Differences between wood and lawn soils (OC + tot N):** Effects of the two types of vegetation **+** urban lawn mowing regime **+** exportation of the clipped grass.

Trace metal concentrations

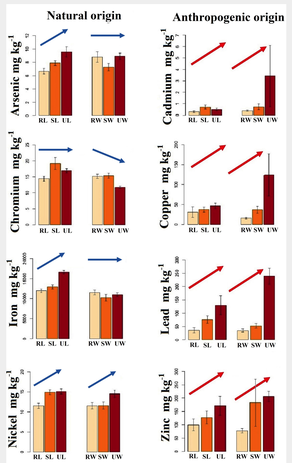


Figure 2 - Mean values (with SE) of TM topsoil's content in lawns and woods along the urban pressure gradient (As: *arsenic*, Cd: *cadmium*, Cr: *chrome*, Cu: *copper*, Fe: *iron*, Ni: *nickel*, Pb: *lead* and Zn: *zinc*).

- Varimax rotation **+** Enrichment Factors (EF) (data not shown):

➢ **2 TM groups (Figures 2)**

Natural origin	Anthropogenic origins
(As, Cr, Fe, Ni)	(Cd, Cu, Pb, Zn)
=	=
Lithogenic source	Traffic road source

+
Second source for Cd
=
Industrial activities of Paris region
↓
Cement plants

- Urban woods → **++++++**

Individual, overall degree of soil contaminations / pollutions

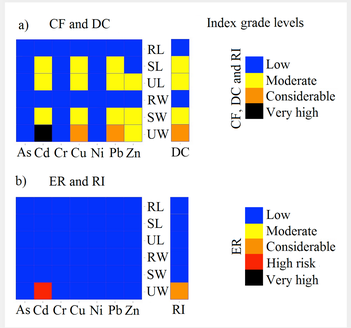


Figure 3 - Heat map of (a) individual TM contamination factor (CF), overall TM degree of contamination (DC), (b) TM pollution degree through the individual TM potential ecological risk index (ER), overall TM ecological risk (RI), in lawns and woods along the gradient of urban pressure. (As: *arsenic*, Cd: *cadmium*, Cr: *chrome*, Cu: *copper*, Ni: *nickel*, Pb: *lead* and Zn: *zinc*).

- Main explication of individual and overall levels of TM contamination and risk (*i.e.* pollution level):

Urban pressure gradient
↓
Anthropogenic TMs → **++++++**

- High levels of individual and overall contamination and risk, the associated grades of individual risk (ER):

↓
Urban woods
=
Cd concentration → **"high risk"**
+
"Considerable" level of pollution
↓
Legacy of the historical management of soils in the Paris region **+ higher age** of urban wood soils.

7 Conclusion

- **Factors influencing TM soil concentrations and enrichments, especially anthropogenic TMs, in the Paris region are: (1) the gradient of urban pressure (*i.e.* human activity proxy), (2) the land-use-types but in a lesser extent. (3) Difference between woods along the urban pressure gradient is likely due to the legacy of the historical management practices of urban woods (importation of market garden soils rich in organic matter, and irrigation with wastewater).**
- **Anthropogenic concentrations of most TMs in urban area are either equivalent or above regulatory reference values and suggest that a long term monitoring of TM concentrations should be initiated.**
- **Urban woods require careful attention: (1) they present high TM concentrations and risks for biological communities, in particular for Cd; (2) they exhibit specific physico-chemical characteristics (high sand and organic matter contents) that could strongly increase the TMs toxicity; (3) they are very frequented by the inhabitants of the region. Besides, the development of urban agriculture in Paris region could increase the risks incurred by its inhabitants due to soil pollution by TMs.**
- **Other studies are necessary to understand the dynamic of TM in soils of the region. This should involve studying: (1) all land-uses (not only lawns and woods) including substrates that are made for green roofs and all forms of urban agriculture, (2) the subsoil and not only the surface soil layer, (3) factors involved in the dynamics of TM, *e.g.* factors determining the deposition and the loss of TM, (4) factors increasing the bioavailability of TM (*e.g.* chemical TM forms) and subsequent risks for humans.**

Acknowledgements

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