Atmospheric deposition in an urban area: implications for assessing the effects of hazardous air pollutants

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ABSTRACT

Pollutants emitted to the atmosphere in urban areas have indirect effects through deposition onto the ground, which, over time, could negatively affect the quality of soil, plants, water and groundwater. In this baseline study, evaluation of topsoil contamination in an urban area of France has been carried out to correlate concentrations observed in the soil with the local air emission sources. The analytical program is an extensive study carried out over a 200 km² area and the results confirm pronounced anthropogenic contributions to the geochemical background for some metals (Cu, Zn, Pb, and Hg) over the entire area under assessment. In addition, PAH concentrations in topsoil have been noted to be significantly higher around heavily trafficked areas, confirming the contribution of road traffic. The contribution of domestic combustion and industrial sources has also been highlighted with elevated concentrations of dioxins and furans; with some sites in exceedance of current international soil guidelines. The results confirm the significant contribution of anthropogenic deposition from former and present-day industrial and road traffic sources to soil composition in an urban area. The high concentrations of trace metals and other hazardous pollutants in many urban soils in inner-city areas give rise to concerns about potential human health effects through ingestion of soil and vegetables grown locally.

Keywords: contamination, urban, topsoil, air pollutants, deposition

INTRODUCTION

It is widely recognised that precipitation scavenging, dry deposition, and re-suspension are significant mechanisms affecting the transport of hazardous air pollutants (Koester *et al.* 1992, Kaupp and McLachlan 1998). The concentration of trace elements in soils has been extensively investigated over rural and agricultural areas (Baize 1997; Baize 2010) whereas atmospheric aerosols composition and characterisation are mainly investigated in urban areas (Elsass *et al.* 2006). The contribution of atmospheric deposition to the soil is therefore of great scientific interest and has become a major environmental concern in the vicinity of industrial plants as well as at a global scale.

An assessment of soil quality has been carried out over the Urban Community of Strasbourg (CUS), France, which is a major industrial and transport node with poor air quality in a sensitive natural environment (aquifer around 2 m below ground level) extensively used for domestic and large scale agriculture. The study aims to provide data to evaluate potential risks to public health.

The study presented here relates to the analysis of soil samples from 20 sites for metallic trace elements, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), volatile organic compounds (VOCs), agrochemical products, dioxins and furans.

The results of this study are then discussed comparing the evolution of regulations in France with the applicable New Zealand regulations for assessing the effects of hazardous air pollutants or contaminated land.

ENVIRONMENTAL SETTINGS

Physical and climatic setting

Strasbourg is located in the Alsace province in the northeast corner of France. It is the eleventh largest city in France with a population of around 450,000. The Urban Community of Strasbourg (CUS) extends over a 300 km² area. Strasbourg is situated on the bank of the Rhine River, which forms the international border with Germany. The Rhine valley forms a natural and industrial corridor between the Vosges mountains (25 km West) and the Black Forest (20 km East).

Due to its location between two mountain ranges, winds are often deflected, particularly the predominant westerly winds. In Alsace, the climate is temperate (continental humid climate, classified as a Cfb Climate) which is similar to the New Zealand climate according to the Koeppen-Geiger classification updated by Peel *et al.* (2007).

The average annual precipitation is low (632 mm y^{-1}) and mainly occurs in the form of snow (30 days y^{-1}) or violent storms (29 days y^{-1}) typically in early and late summer. A significant temperature range (-15°C in winter and +35°C in summer) occurs over the year. Dominant winds (wind NNE-SSW) are not strong (average of 2.9 m s^{-1} over 10 years measured at the airport, located out of the city) and pollution does not disperse well, especially during winter foggy days (56 days y^{-1}) when a relatively low inversion layer often exists. The number of sunshine hours is below the national average around 1640 h y^{-1} (Météo France 2008).

Geochemistry and geology

The CUS area geology (BRGM 1971) comprises the main Rhine riverbed (mainly constituted of sands and gravels from the Rhine covered by overflow silts), a layer of loess in the North-West and the riverbed of the Bruche (composed of gravels and silts from the Vosges).

However, the surface soils in the city mainly consist of modified and mixed soils with some anthropogenic residues. Former and current industrial sites along with activities likely to have contaminated the soil are extensively identified and listed by the national government (BRGM 2011a, b).

Air pollutant emission sources

Strasbourg is an important centre for manufacturing and engineering, as well as road (A4, A35 and A351 motorways), rail and river transport. The port of Strasbourg is the second largest on the Rhine. The main industrial activities identified (MEDD 2011a,b) as having a significant discharge of contaminants to air are: thermal power stations, printing industries, paper mill industries, petroleum refineries, petrol storage depots, breweries, industrial and domestic waste incinerators, metal treatment and manufacturing, wastewater treatment. The main heavy industries are located adjacent to the Rhine. Two significant thermal power stations no longer operational are also reported (MCC 2011). On the German (east) bank of the Rhine, the main industries are steelworks and a biomass power plant. Solid fuel home heating is carried out in many homes which also contributes to air pollution in the area. The locations of the main air pollutant emission sources are presented in Figure 1.

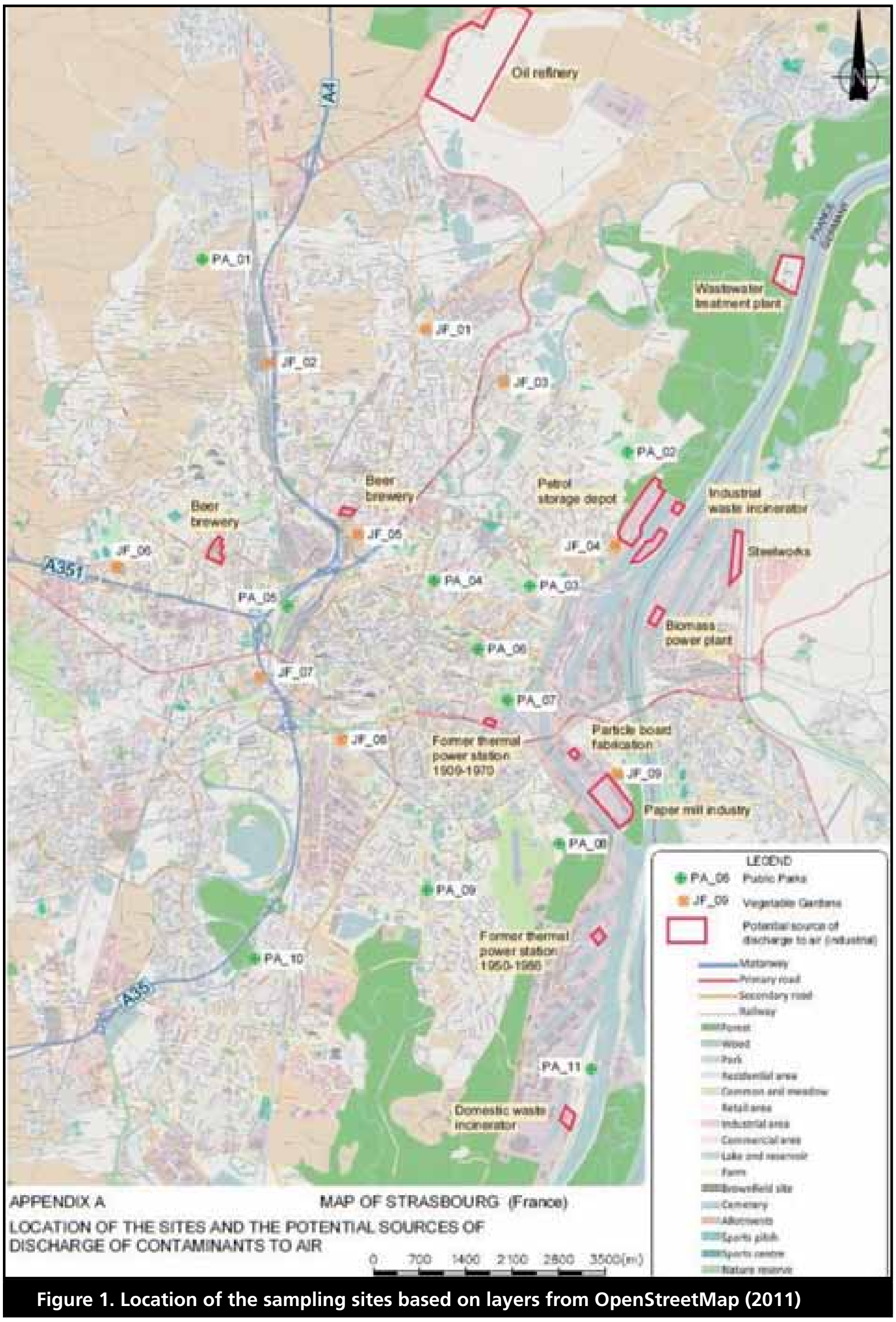

Figure 1. Location of the sampling sites based on layers from OpenStreetMap (2011)

DESIGN OF THE STUDY

Twenty sites were sampled over the entire area without considering their proximity to the potential air pollutant emission sources: 9 vegetable gardens (labelled JF) and 11 public parks (labelled PA). The locations of key sites are shown in Figure 1. Within these sites, the sampling locations selected were in areas covered with grass, subjected to normal rainfall (*i.e.* not below a tree) and without any treatment or modification based on historical assessment prior to sampling.

Top soils were sampled using a hand core drill after removing the surface grass (light scraping). Sampling methodologies were adapted from relevant standards (AFNOR 1992; Laperche and Mossmann 2004; INVS 2005) and analytical specifications for the different elements. The main aspects included:

- Metals: creation of a composite sample (US EPA 2007) from 4 individual samples over a 2 x 2 m square;
- Polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), volatile organic compounds (VOCs) and agrochemical products: extraction of 2 samples at 0-25 cm depth and storage in a glass bottle without breaking the core;
- Dioxins and furans (only for 10 sites): sampling at 0-10 cm depth and storage in a glass bottle without breaking the core.

All samples were kept in an icebox below 4°C and sent to the laboratories for analysis within 24 hours. Testing of the samples was carried out by laboratories accredited by the French Committee of Accreditation, using relevant analytical methods (inductively coupled plasma atomic emission spectroscopy (ICP-AES), cold vapour atomic absorption spectrometry (CV-AAS), electrothermal atomic absorption spectrometry (ET-AAS), high resolution gas chromatography (HRGC) and high resolution mass spectrometry (HRMS).

On site, semi quantitative evaluation was carried out with a portable X-Ray Fluorescence apparatus (Niton® XL-723S). Following the specific calibration of the instrument (Laperche 2005), and a cross comparison with the analytical results, only a few elements (Zr, Sr, Pb, Zn, Fe) were considered to have sufficient precision and consistency to justify statistical analysis. For these elements, an analysis was carried out to compare the concentrations observed in the soil surface (top of the core) with concentrations at depth (side of the core at a depth of 5 cm).

RESULTS AND ANALYSIS

Metals

Metal concentrations observed in top soil are presented in Table 1. For a few elements (As, Co, Cr, Ni), statistical analysis indicated that the coefficient of variation (CV) was low and therefore the concentrations followed a normal distribution. Previous geochemical investigations in the area (Elsass and Kramers 2003) confirmed that the observed concentrations were close to the geochemical background and could be significant for some chemicals (median concentration for Cr is 61 mg kg^{-1} dry wt compared to the median concentration in the top soil across France which is 38.3 mg kg^{-1} dry wt, as described by Baize (2010).

For other elements (Cu, Hg, Pb, Zn), the coefficient of variation was higher with a few high values above international guidelines. This is likely to be due to the geochemical background being affected by an anthropogenic contribution as similarly demonstrated in New Zealand (Kennedy 2008).

Pb is a contaminant of concern due to historic diffuse emissions of fuel containing tetraethyl lead (between 1980 and 2000). However, a link between the proximity to the main roads and the highest Pb concentrations was not established as three of the samples (JF_03, JF_09, PA_09) with the highest lead concentrations were from sites located away from main roads.

Although the 0-25 cm layer is commonly used to assess the top soil contamination (Laperche and Mossmann 2004), evaluation of metal concentrations at different depths was carried out on site to provide a vertical profile. Correlation graphs for XRF analysis

Table 1 : Metal concentrations observed in topsoil

	Metals concentrations in the soil samples [mg kg^{-1} dry wt]														
Elements	As	Cd	Co	Cr	Cu	Hg	Li	Ni	Pb	Sr	V	W	Zn	Zr	pH
Limit of Quantification (LQ) [mg/kg dry wt]	*5*	*2*	*5*	*10*	*5*	*0.1*	*10*	*10*	*10*	*5*	*10*	*10*	*5*	*20*	*0*
Sites (JF = Vegetable Garden / PA = Public Park)															
JF 01 ML 1	8	2	12	72	36	< LQ	42	30	58	139	57	35	280	274	7.9
JF 02 ML 1	18	< LQ	13	76	111	0.1	34	32	74	166	56	33	169	359	7.9
JF 03 ML 1	14	< LQ	11	54	61	0.5	36	23	405	210	38	28	242	170	7.7
JF 04 ML 2	9	< LQ	10	57	23	< LQ	32	21	35	270	43	25	102	149	7.9
JF 05 ML 1	12	< LQ	13	60	64	0.5	33	28	182	170	45	29	196	234	8
JF 06 ML 2	12	< LQ	12	71	31	0.1	44	28	155	144	55	37	88	316	8
JF 07 ML 1	20	2	15	63	55	0.5	44	32	132	110	55	35	330	212	7.6
JF 08 ML 2	13	< LQ	11	99	57	0.3	34	23	146	155	43	29	299	193	7.6
JF 09 ML 2	12	< LQ	13	59	45	0.3	32	26	328	217	40	22	222	113	7.8
PA 01 ML 2	10	< LQ	13	77	19	< LQ	35	28	19	167	50	34	65	411	8.1
PA 02 ML 1	7	< LQ	9	46	19	0.2	26	15	61	203	33	22	68	132	7.9
PA 03 ML 2	10	< LQ	11	58	21	< LQ	35	27	118	227	46	29	77	141	8
PA 04 ML 2	10	< LQ	13	72	23	< LQ	35	31	31	83	55	38	71	399	7.8
PA 05 ML 2	11	< LQ	11	62	27	< LQ	35	26	40	163	42	32	84	242	8.1
PA 06 ML 1	8	< LQ	9	54	76	0.2	27	18	174	214	29	24	122	156	7.9
PA 07 ML 1	14	< LQ	15	82	81	0.9	36	35	168	106	55	34	174	336	7.9
PA 08 ML 1	10	< LQ	11	53	34	0.2	34	23	65	199	42	28	105	105	8
PA 09 ML 2	9	< LQ	10	59	23	< LQ	34	27	196	164	43	29	78	157	7.9
PA 10 ML 1	11	2	11	132	83	< LQ	33	30	102	164	43	30	206	231	8.1
PA 11 ML 1	6	< LQ	10	59	18	< LQ	33	19	16	274	44	29	71	133	8.2
Number of quantification	*20*	*3*	*20*	*20*	*20*	*11*	*20*	*20*	*20*	*20*	*20*	*20*	*20*	*20*	*20*
Minimum	6	< LQ	9	46	18	< LQ	26	15	16	83	29	22	65	105	7.6
Maximum	20	2	15	132	111	0.9	44	35	405	274	57	38	330	411	8.2
Arithmetic mean (μ)	11.2	< LQ	11.7	68.3	45.4	0.3	34.7	26.1	125.3	177.3	45.7	30.1	152.5	223.2	7.9
Standard deviation(σ)	3.4	-	1.7	19.4	26.9	0.2	4.5	5.2	101.6	50.2	7.9	4.6	86.3	96.4	0.2
Coefficient of variation (CV)	0.3	-	0.1	0.3	0.6	0.7	0.1	0.2	0.8	0.3	0.2	0.2	0.6	0.4	0.0
NZ NES SCVs (health)	As	Cd (pH 5)		Cr(VI)		Inorganic Hg comp.			Inorg. Pb						from MfE (2011)
Rural residential / lifestyle block 25% produce	17	0.8	-	290	No Limit	.	-	-	160	-	-	-	-	-	-
Residential 10% produce	20	3	-	460	No Limit	310	-	-	210	-	-	-	-	-	-
High-density residential	45	230	-	1500	No Limit	1000	-	-	500	-	-	-	-	-	-
Recreational	80	400	-	2700	No Limit	1800	-	-	880	-	-	-	-	-	-
Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health															
Agricultural	12	1.4	-	64	63	6.6	-	50	70	-	130	-	200	-	-
Residential / parkland	12	10	-	64	63	6.6	-	50	140	-	130	-	200	-	-

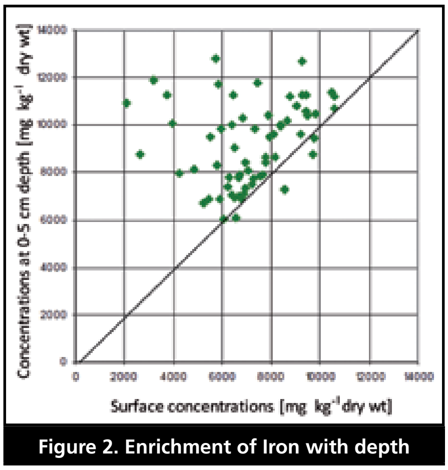

Figure 2. Enrichment of Iron with depth

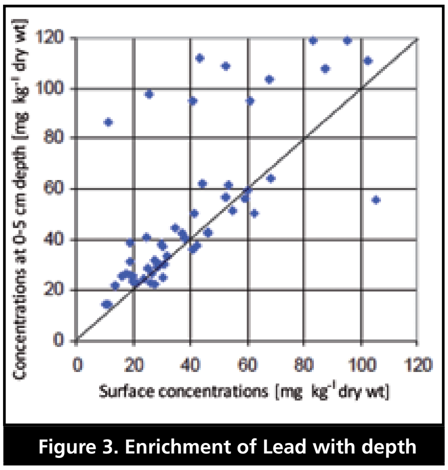

Figure 3. Enrichment of Lead with depth

indicated that for Fe there was an increase in concentration with depth in some samples (Figure 2) and in a small number of localised areas distributed over the entire area for Pb (Figure 3), with a lower tendency for Sr and Zr. Cu and Zn results showed no clear trend. Uncertainties on the XRF analysis were not calculated in that study but are generally within ± 20% for these elements in soil as already investigated by Laperche and Mossmann (2004) and Bouzonville *et al.* (2008).

The leaching of metals is hard to quantify over such a wide area as the mobility of chemical elements is also affected by other parameters (pH of the soil and the rain, partition coefficient as described in US EPA (2005)). Rainfall analysis over the city indicates a mainly acidic pH (Herckes et al. 2001), although the sites sampled were slightly basic. The enrichment of Fe with depth could therefore be linked to the higher mobility of that element in the soil with acid rain. This observation was consistent with less mobile elements (Cu, Zn, Pb) remaining longer in the topsoil.

On some sites (JF_07, PA_07, JF_03), the obvious increase of the Pb concentration with depth was not easy to explain, apart for JF_07 which was located near a major intersection of highways A35 and A351.

Polycyclic Aromatic Hydrocarbons (PAHs)

Six different PAHs were analysed (fluoranthene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeopyrene, benzo[g,h,i]perylene). One or more PAHs were detected at 18 of the 20 sites. PAH concentrations observed in top soil are presented in Table 3. The concentration range was wide with high concentrations observed on some sites for B[a]P (JF_05 : 6720 µg kg^{-1} dry wt, JF_07 : 2070 µg kg^{-1} dry wt, JF_01 : 1200 µg kg^{-1} dry wt).

The analysis of contribution of the different PAH compounds to total PAH concentration indicated a consistent pattern across all the sites. Fluoranthene was, on average, 32% of the total PAHs, while benzo[b]fluoranthene accounted for 19% and benzo[a]pyrene (B[a]P) for 18%. This was consistent with concentrations observed in ambient air monitoring (ASPA 2010), indicating that the PAHs may have a common origin.

In order to evaluate the potential road traffic contribution to PAHs, correlation between the total concentration and the proximity to the source was carried out (refer Table 2). The results confirmed that the sites located around heavily trafficked roads had significantly higher concentrations (around one order of magnitude) than in other environments. Calculation of PAHs relative to distribution in soils (Yunker *et al.* 2002) confirmed the origin from a mixed source of wood based and petroleum based combustion fuels, results similar to those observed in Christchurch, New Zealand (Environment Canterbury 2007).

In addition, the average B[a]P concentrations were higher around residential areas. This is consistent with the observation that 95% of the ambient B[a]P in air in this area comes from wood burning for residential heating (ASPA 2010).

Volatile Organic Compounds (VOCs)

A range of 50 other VOCs were analysed on all the sites including among others: BTEX, chloroform, styrene, naphthalene. However, the limit of quantification of those were between 20 and 100 µg kg^{-1} dry wt depending on the product, and were too high to allow these substances to be quantified. Therefore, these compounds were not considered further in the study.

Agrochemical products

Pesticides and insecticides were randomly detected on the sites. However, considering the substances detected, and their location, it can be noted:

- JF_03 showed 26.7 µg kg^{-1} dry wt of dieldrin even though its use has been banned since 1994 (INERIS 2007). Other substances (including aldrin) are all below the limit of quantification, indicating the usage of dieldrin at that particular location.
- JF_06 showed 2.6 µg kg^{-1} dry wt of 1,2,3-TCB and 5.5 µg kg^{-1} dry wt of 1,2,4-TCB. These products have been detected only at this location which is likely to be due to the application of pesticides on the fields nearby (fields located 300m W of the site).
- Hexachlorocyclohexanes (HCH) were always below the LQ (between 2 and 5 µg kg^{-1} dry wt) despite previous investigations indicating that some of these pesticides are present in the atmosphere of Strasbourg at a concentration between 345 and 3940 pg m^{-3} of total g-HCH (Sanusi *et al.* 1998).
- On seven sites (JF_02, JF_07, JF_08, PA_02, PA_03, PA_09, PA_10), dichloro-diphenyl-trichloroethane (DDT), dichloro-diphenyl-dichloroethylene (DDE) and dichloro-diphenyl-dichloroethane (DDD) were identified. Only the p,p' isomers of these products have been quantified, corresponding to the technical grade DDT (ATSDR 1994). Despite DDT having been banned as a pesticide in Europe for over 30 years, DDT and its breakdown products, DDE and DDD (Pirnie *et al.* 2006) were still present in the soil. This is also consistent with results found in New Zealand (Boul 1995).

The quantified elements confirmed the persistency of agrochemical products but also highlighted contamination over the entire area, even at some distance from the potential agricultural use of the compounds.

Non-Dioxin-Like PCBs (NDL-PCBs)

In evaluating the contamination situation, seven congeners (# 28, 52, 101, 118, 138, 153, and 180) were chosen as indicators for the occurrence of NDL-PCBs. NDL-PCBs were detected over 8 sites but the values were low for most of the sites. The maximum was observed in JF_03, (Σ PCBs of 112.7 µg kg^{-1} dry wt) but the origin of that concentration was not established.

The distribution of the different congeners over the sites was similar and showed that the LPCB (Σ cong. 28, 52, 101 = lower chlorinated PCBs) were less represented than the HPCB (Σ cong. 118, 138, 153, 180 = higher chlorinated PCBs) as illustrated in the Figure 4. The relative distribution of the congeners was consistent with other studies on soils in urban areas (UBA 2007). This is likely to be due to the decreasing solubility in water of the higher chlorinated congeners (Shiu and Mackay 1986) which therefore have a lower tendency to leach than the lower chlorinated congeners (FAO 2000).

Dioxins and furans

Ten sites were sampled and analysed for polychlorinated dibenzodioxins (PCDD) and polychlorinated dibenzofurans (PCDF). The concentrations are reported in grams of toxic equivalents (TEQ). This method accounts for the differences among the 17 selected compounds by estimating toxicity of the individual dioxin compounds using a toxic equivalency factor (TEF). The 1997 WHO-TEF was used in the study (Van den Berg *et al.* 1998).

The sites located in a residential area, without any industrial sites in the vicinity, showed concentrations around 2 pg I-TEQ g^{-1} which is consistent with the mean values across France which range between 1.9 and 2.2 pg I-TEQ g^{-1} as described by Bodénan and Michel (2008).

The highest concentrations observed were mainly located close to potential industrial emission sources of dioxins and furans:

- JF_04, 4.3 pg I-TEQ g^{-1} located in a heavy industrial area surrounded by an incinerator (700m north-east), an oil depot and steel production plant (1000m east);
- PA_11, 6.14 pg I-TEQ g^{-1} located in a heavy industrial area, 800m north of a waste incinerator;
- JF_03, 8 pg I-TEQ g^{-1} located in a residential area but around 50m east from a municipal boiler;
- JF_09, 11 pg I-TEQ g^{-1} located in an industrial area 300m east from a major paper mill.

In some vegetable gardens, the concentrations of PCDD/PCDF observed in the top soil exceeded the international soil guideline values (British Soil Guideline Value: 8 pg I-TEQ g^{-1} for a residential use based on UK Environment Agency (2009), the German Soil Guideline Value: 5 pg I-TEQ g^{-1} as described in BLAG (1992) and the Canadian Soil Quality Guideline for the Protection of Environmental and Human Health: 4 pg I-TEQ g^{-1} for a residential or agricultural use as described in CCME (2007)). This geographical distribution confirmed the contribution of the atmospheric pollutants from local sources and its tendency to have an impact in the direct vicinity of the emission source.

Results summary

The results of the study indicated widespread contamination of soil through atmospheric deposition in the urban area. The study highlighted the contribution of the geochemical background over the entire area for some metals (Cu, Hg, Pb, Zn) and pesticides (DDT, slowly breaking down to DDE and DDD).

Higher concentrations of PAHs were noted directly around the main motorways but also around the historical thermal power plants using coal and heavy fuel oil and in the northern part of the city around the oil

Table 2. Statistics of the PAHs per type of activities around the sites.

Total PAHs [μg kg^{-1} dry w]	Predominant activity in the vicinity of the site			
	Road traffic	Industrial	Natural	Residential
Minimum	287	<5	6.3	310
Maximum	42,000	2,530	2,880	4,560
Average	10,979	885	1,011	1,786
Median	5,744	124	579	772
Standard deviation(σ)	16,028	1,426	1,276	1,682
Coefficient of variation (CV)	1.5	1.6	1.3	0.9

Table 3. Statistics of the PAHs and PCDD/PCDF.

Chemical compounds analysed	Unit	Number of detection	Minimum	Maximum	Artihmetic mean	Median	Coefficient of variation (CV)
Dry matter content	%		78	91	85	84	-
Non-Dioxin-Like PCBs (NDL-PCBs)							
PCB 28	μg kg^{-1}	0	<2	<2	-	-	-
PCB 52	μg kg^{-1}	2	<2	29	2	-	3.5
PCB 101	μg kg^{-1}	3	<2	303	16	-	4.2
PCB 118	μg kg^{-1}	4	<2	138	8	-	3.8
PCB 138	μg kg^{-1}	7	<2	809	43	-	4.2
PCB 153	μg kg^{-1}	8	<2	887	47	-	4.2
PCB 180	μg kg^{-1}	5	<2	722	38	-	4.3
PCB totaux	μg kg^{-1}	8	<2	2,888	154	-	4.2
Total hydrocarbons and polycyclic aromatic hydrocarbons (PAHs)							
FLUORANTHENE	μg kg^{-1}	19	<5	12,900	1,399	247	2.1
BENZO(B)FLUORANTHENE	μg kg^{-1}	18	<5	10,000	850	140	2.6
BENZO(K)FLUORANTHENE	μg kg^{-1}	18	<5	3,830	419	72	2.1
BENZO(A)PYRENE	μg kg^{-1}	18	<5	6,720	699	146	2.2
INDENOPYRENE	μg kg^{-1}	18	<5	4,350	447	81	2.2
BENZO(GHI)PERYLENE	μg kg^{-1}	18	<5	4,100	437	80	2.1
Total PAHs	μg kg^{-1}	19	<5	41,900	4,254	750	2.2
Total Hydrocarbons	mg kg^{-1}	20	3	573	54	21	2.3
Polychlorinated dibenzodioxins (PCDD) and polychlorinated dibenzofurans (PCDF)							
PCDD/PCDF (pg I-TEQ/g WHO 1997)		10	1.6	11.0	4.2	2.5	0.8

refineries and residential housing using wood fired heating.

Agrochemical products that had been banned for many years were identified over the entire area, similar to the situation for some of these substances in the air. The persistence in topsoil of some pesticides like DDT is significant and therefore has the potential to be reemitted to the atmosphere.

PCDD/PCDF also had significantly higher concentrations in the vicinity of the emission sources (incinerator, paper mill) even though the impact appeared to be restricted to the immediate area surrounding the source. Locating vegetable gardens in the vicinity of these areas should therefore be considered in the light of these results.

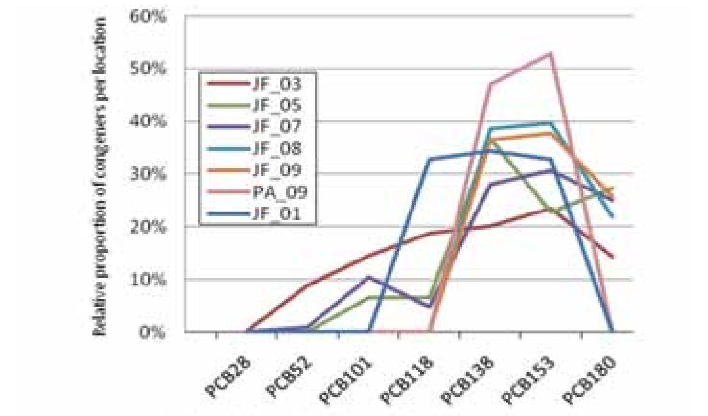

Figure 4. Relative distribution of the 7 PCB congeners

DISCUSSION

Uncertainties

The link between concentrations observed in the soils and long term air discharges is difficult to establish due to the following:

- Databases and emission inventories that have been developed by the regulatory authority (MEDD 2011(a,b)) to assess ambient air quality and long term soil contamination (from dry and wet depositions), do not take into account the emissions from historical contributors or diffuse sources (agriculture, domestic heating). In some cases, the contribution might be significant, as the former industrial practices (coal thermal power stations) were not as well regulated as they are now.
- Industrial accidents should also be taken into account as gas releases or fire smoke may have a significant impact on air quality. Over 71 accidental industrial fires are listed in the ARIA Database (MEDD 2011(c)) for Strasbourg with likely associated emissions of heavy metals, PCDD/PCDF and other similar pollutants.
- Topsoil is an appropriate medium to quantify the deposition of air contaminants (Durif 2004) over a long term exposure. However, the integrity of the topsoil (absence of modification or local contamination) is difficult to guarantee, so historical review of the site and observations made while sampling are critical to ensure appropriate samples are collected.

Transposition to New Zealand

As in New Zealand, sources of discharge to air in Strasbourg are mainly related to industry, transport and residential wood burning (winter). The general climate observed in New Zealand is similar to the one observed in Alsace and therefore, the transport of pollutants into the atmosphere is ruled by the same mechanisms and phenomena (winter fog, low inversion layer). Whereas vegetable gardens are often grouped together in Strasbourg in community allotments, New Zealand tends to have more individual housing with gardens, including vegetable gardens, within the city boundaries and sometimes these are close to industrial areas or heavily trafficked highways.

Similarities in the sources of emissions, the transfer (transport and deposition) of pollutants, the population distribution and the use of land in Strasbourg suggests that the results of this study are likely to be relevant to the situation in New Zealand.

Health risk assessment considerations

The study also demonstrated the importance of taking into account concentrations observed in soil through deposition as part of the health risk assessment process. To evaluate the potential health effects of an air discharge, practitioners often compare the predicted values with threshold ambient air values (MfE 2011). This study indicated that deposition of air contaminants is significant over time and therefore the ingestion of various contaminants from the soil or from vegetables grown locally needs to be taken into account.

Furthermore, the measured concentrations have highlighted local characteristics of soils in this particular area in relation to the geochemical background (As, Cr) and anthropogenic sources (Pb, B[a]P, dioxins and furans), which need to be considered in the exposure calculations as part of the evaluation process.

Since 2003, Environmental Impact Assessment is required in France to quantify human health risk (INERIS 2003), taking into account the toxicological effects of different substances as well as relevant exposure pathways. The assessment of effects from air discharges is no longer restricted to the contaminants discharged to air by the activity but should encompass:

- the deposition of contaminants onto the soil and vegetables; as well as
- the wide range of contaminants present in the urban environment, whose chronic effects are likely to be cumulative.

Unlike the NZ approach (MfE 2010), the French regulation on contaminated land changed in 2007 from the comparison of results with guidelines and threshold values related to the use of land to a case by case approach that takes into account the local geochemical background together with a focus on the differences between the background and the site observations (MEDD 2007).

The results of this study provide valuable information in the assessment of the local geochemical background of soils which is significantly different from the national or regional background. It also demonstrates that atmospheric contributions need to be taken into account during contamination assessments, as the products observed in soils are made from a wide range of elements which might be persistent in the topsoil. These results could also be transposed to other cities with similar land uses.

Over the last ten years, the French regulations changed significantly to require a uniform approach when quantifying human health effects of emissions from industry requiring consent and from contaminated land. That change of approach is the result of the acknowledgement that in several locations, and especially in urban areas, people are exposed over time to multiple substances through multiple exposure pathways and that the effects are often cumulative.

Therefore to assess the effects and quantify the health risk for a population (whatever the situation) a specific conceptual scheme needs to be developed justifying the prevalence of the different pathways for the different substances. An example of a conceptual scheme showing the significant exposure pathways highlighted by this study is presented in Figure 5.

Guideline values, threshold values or standards are therefore no longer applicable as these are developed for specific and non exhaustive exposure pathways (as detailed in MfE 2010, TCEQ 2006 and CCME 1999) which often differ from local situations.

Building a site specific conceptual scheme allows consideration to the contribution of the assessed source of contamination or discharge to air, as well as the existing local background (ambient air and concentration in the soil, vegetables, ground water…) and the local use of the site. Exclusion of an exposure pathway should then be discussed along with the uncertainty and potential impact on the quantification of human health risk.

CONCLUSION

The results of the investigations indicated widespread contamination of soil through atmospheric deposition in the urban area of a wide range of chemicals. The results confirmed the presence of significant concentrations of chemicals in the vicinity of the emissions sources, in addition to the contribution from diffuse sources over a wider area. The persistency of some chemicals (lead, agrochemical products) in soil has also been highlighted.

Populations in urban areas are increasingly exposed to multiple hazardous substances through multiple pathways. It is therefore necessary to review guidelines and policies to take into account that fact and reduce potential health risks for the people living in these areas.

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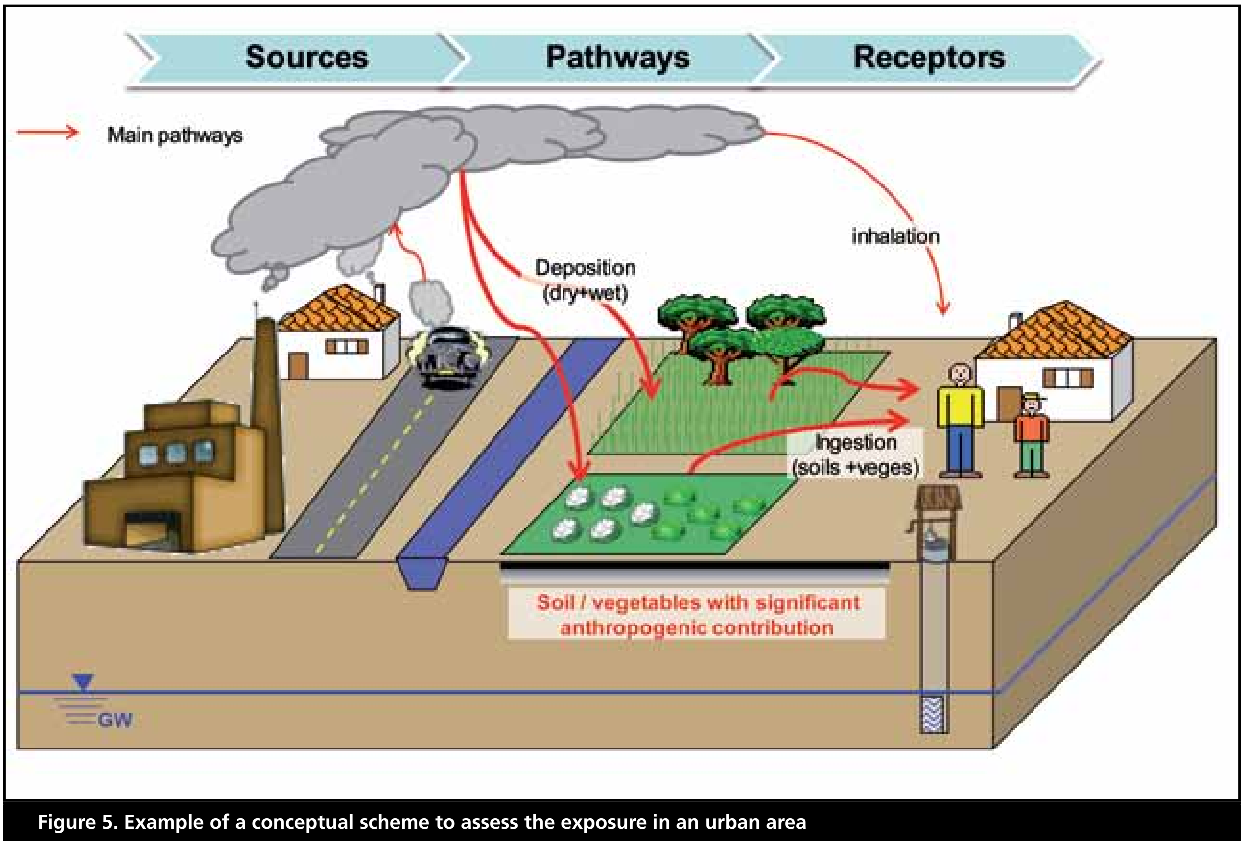

Figure 5. Example of a conceptual scheme to assess the exposure in an urban area

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