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## A street deposit sampling method for metal and hydrocarbon contamination assessment

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### Abstract

Urban surface contamination, by atmospheric deposits as well as human activities, is a major concern for urban pollution management. Besides coarse street deposits which are clearly perceived and easily removed, suspended solid (SS) surface loads and contamination by heavy metals and hydrocarbons are rarely assessed although they could be of major importance with regards to combined or separate sewer overflow (CSO and SSO) impacts. Both dry and wet vacuum sampling procedures have been first compared, in the laboratory, using dry and sieved clay or street deposits. Then the wet vacuum sampling procedure has been refined, coupling the injection of water and the hand-brushing of the surface prior to its vacuum cleaning, and evaluated on a car parking area close to the University. Finally this procedure has been assessed in Béarn Street within the 'Le Marais' district in Paris centre, and 34 samples have been analysed for metal and eight for aromatic hydrocarbon contamination. Heavy metal concentrations (0.1–1.7 g kg<sup>-1</sup> dry wt. Cu, 0.9–6.1 g kg<sup>-1</sup> dry wt. Pb and 1.5–4.6 g kg<sup>-1</sup> dry wt. Zn) within street deposit samples collected in Paris centre, indicate a high contamination, especially for copper and zinc, as compared to reported data. Total polyaromatic hydrocarbons (PAHs) are in the 3–11 mg kg<sup>-1</sup> dry wt. range, thus approximately 10 times less contaminated than dry atmospheric deposits. This paper presents data obtained and discusses the difficulties encountered when sampling street deposits in busy areas of a city like Paris. The water jet street cleaning procedure used by Paris city workers was tested for its efficiency, by comparison of surface loads before and after the cleaning procedure. Although solids cleaning efficiency is highly variable (20–65%) and somewhat higher

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for particles larger than 100  $\mu\text{m}$ , particulate metal cleaning efficiency is even more variable (0–75%) and particulate PAHs appear not to be significantly removed. © 1999 Elsevier Science B.V. All rights reserved.

*Keywords:* Urban deposits; Street; Particles; Metal; Hydrocarbons; PAH; Sampling method; Vacuum; Urban catchment; Street cleaning; Water jet

## 1. Introduction

Urban surfaces receive deposits issued from more or less remote sources (car traffic, industries, waste incineration, domestic heating), through atmospheric transport as well as from local human activities. The sampling of dry and wet atmospheric deposits can be easily achieved either directly or through a roof outlet. The sampling of street and footpath deposits might be even simpler but it is actually much more difficult to achieve if the sample representativeness is taken into account. Soils are generally much more polluted in the immediate vicinity of major roads (Harrison and Johnston, 1985; Hewitt and Rashed, 1991), which suggests that a significant part of pollution due to traffic has a very short residence time in the atmosphere, and cannot be measured by atmospheric deposition sampling techniques. However, both remote and locally produced deposits contribute to urban run-off pollution. Their quantity, their composition, but also their physical characteristics (at least their grain size) should be characterised in order to determine their transport under wet or dry conditions, related both to urban wash-off as well as to the efficiency of usual street cleaning procedures.

Street deposits have been mostly sampled by sweeping (Duggan, 1984; Gulson et al., 1994; Madany et al., 1994; Ogunsola et al., 1994; Al-Rajhi et al., 1996) or brushing (Archer and Barratt, 1976; Fergusson and Simmonds, 1983; Davies et al., 1987; Culbard et al., 1988). Since these techniques may discriminate between finer and coarser particles, vacuum sampling has also been suggested (Butler et al., 1992; Ball et al., 1996). Besides dry sampling procedures, alternative methods for collecting street deposits have used a water jet connected to the fire hydrant or a rain simulator, they showed collection efficiencies larger than sweeping or brushing (Sartor et al.,

1974; Ellis, 1986; Ellis et al., 1986) but they require heavy equipment. It was decided to develop a lighter wet method based on a domestic ‘floor and carpet’ wet vacuum cleaner and to compare its collection efficiency with that of a standard vacuum cleaner. After validation of these sampling procedures both in the laboratory and in a car-park area, street deposit surface loads and their contamination were assessed within the experimental urban catchment of central Paris in the ‘Le Marais’ district (Gromaire-Mertz et al., 1998a). As this experimental catchment contained atmospheric deposits (Garnaud et al., 1998) as well as roof, street and yard run-off water sampling devices, it was possible to compare the contamination of several types of particles inside this densely urbanised catchment. Finally, we attempted to assess the efficiency of one of the street cleaning procedures commonly used within Paris City, i.e. the water jet on road and footpath.

## 2. Material and methods

### 2.1. Vacuum cleaners

Two domestic vacuum cleaners have been used: a conventional model for dry and wet surfaces (Kärcher 2001, France) and a floor and carpet model (Kärcher 555c). Both models present the same flow characteristics (58  $\text{l s}^{-1}$ , 150 mbar depression), the latter model being completed with a water jet (1  $\text{l min}^{-1}$  at 1 bar) whose outlet is 1 cm apart from the vacuum inlet (22  $\times$  0.4 cm wide). Both devices have been modified by introduction of a 34-l high-density polyethylene container. In the case of dry vacuum cleaner, this container was initially filled with 1 l of water. Containers were designed to act as hydrocyclons and enable fine particle sample collection. Fi-



Fig. 1. Floor and carpet vacuum cleaner modified for urban deposit sampling: domestic cleaner for floor and carpet (Kärcher model 555c) and high density polyethylene vessel (34 l). Street deposit sampling area is determined by a  $80 \times 80\text{-cm}^2$  plastic frame: here the studied surface is a University laboratory floor covered with dried and sieved sediments.

nally, for field experiments, a 220-V AC generator (2500 W) was used for power supply. As shown in Fig. 1 the sampling area was delimited by a  $80 \times 80\text{-cm}^2$  plastic frame.

## 2.2. Sampling sites

Three sites have been used, two for validation and one for urban deposit characterisation.

The floor of the Cereve laboratory at Créteil was used for the primary experiments. It is made

of  $5 \times 5\text{-cm}^2$  tiles connected with 3-mm wide and approximately 1-mm deep cement junctions.

An asphalt covered car park area close to the University was used for assessing the efficiency of hand-brushing combined with wet vacuum sampling on 25 April 1997, which followed an exceptional period of 50 days without rain, and on 31 May 1997 after 7 days of dry weather, and finally on 7 June 1997 immediately after a heavy rain.

Within the urban experimental catchment set-up at Paris centre in the 'Le Marais' district (42 ha 78% impervious, 12500 inhabitants) (Gromaire-Mertz et al., 1998a), Béarn Street was selected for field experiments, even though it is not situated upstream of any street run-off samplers (Fig. 2). Reasons for this choice are the relatively large roadway width (8 m with gutters) as well as the width of its footpath (2.5 m), with low traffic (approx. 100 vehicles per day) and commercial activity (one school, two restaurants and a police station) and homogeneous surfaces (paved footpath and asphalt road). Two sampling campaigns have been organised in Béarn Street. The first campaign was performed on 12 June 1997, 24 h after a small storm (3 mm total,  $22 \text{ mm h}^{-1}$  maximum — evaluated on 0.2-mm rainfall depth steps — and  $2.7 \text{ mm h}^{-1}$  mean intensity). The second campaign was performed on 19 June, 5 days after a stronger storm (11 mm total, 76 mm

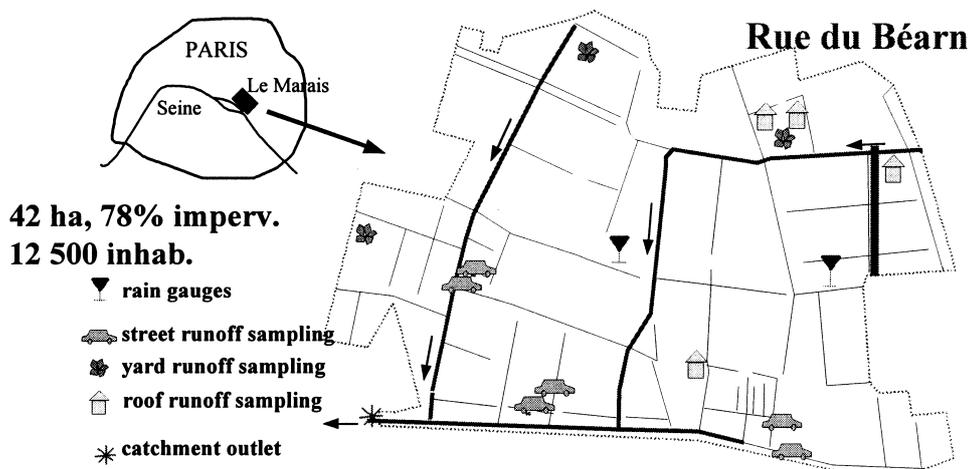


Fig. 2. Urban experimental catchment, at Paris centre, within the 'Le Marais' district and location of Béarn Street (Gromaire-Mertz et al., 1998b).

$\text{h}^{-1}$  maximum and  $4.5 \text{ mm h}^{-1}$  mean intensity). On 19 June 1997 a careful cleaning of Béarn Street was organised with a water jet vehicle, commonly used by the Paris city street management department, in order to assess the street cleaning efficiency with such equipment.

### 2.3. Methods

#### 2.3.1. Collection efficiency assessment on the laboratory floor

A cleaned section of the laboratory floor was given a hand-spread surface load of calcinated and sieved particles consisting of  $0.5\text{--}10 \text{ g m}^{-2}$  of dried and sieved solids: either clay ( $< 50 \mu\text{m}$ ) (kaolin) or  $200\text{--}2000 \mu\text{m}$  gutter sediment collected at the 'Le Marais' experimental catchment site in central Paris. In the case of clay, a suspension in water (approx.  $50 \text{ ml m}^{-2}$ ) was spread on the experimental floor and air-dried. Calcination of 'Le Marais' particles avoids further aggregation of particles and allows a significant evaluation of grain sizes. Both types of particles were sampled twice with both types of vacuum cleaners. SS were collected from the 34-l container, which was further rinsed with 0.5 l water, and the collected suspension was centrifuged at 5000 rev./min during 20 min (Jouan GR 412). Between 0.3 and 6 g of solids were collected from the centrifugation tube, dried and weighed.

#### 2.3.2. Collection efficiency assessment on the University car park

After selection of an apparently homogeneous area of the University car park, the wet sampling procedure was repeated four times on the same area either with or without a hand-brushing step. In each case, 4 l of water were injected and the vacuum inlet was motioned at approximately  $5 \text{ cm s}^{-1}$ , in parallel stripes, along four possible directions inside the area delimited by the  $80 \times 80\text{-cm}^2$  frame. For the hand-brushing step, approximately 250 ml of water was first introduced over one-quarter of the delimited area, particles were hand brushed in the direction of the centre of the frame and this SS slurry was sucked without further water injection. Such injection-brushing-suction procedure was repeated four times before a

'regular' injection-suction step was achieved in one of the four possible directions. Whereas the regular wet vacuum sampling procedure needed approximately 20 min per  $80 \times 80\text{-cm}^2$  unit area, the wet and brush vacuum sampling needed approximately 30 min, taking into account the 34-l container emptying and rinsing time. In both cases SS samples were sieved, centrifuged, air-dried and weighed.

#### 2.3.3. Street deposit sampling

Road, gutter and footpath surfaces were sampled using water jet and hand-brushing, the vacuum inlet being moved only in two opposite directions at a lower velocity (approx.  $2.5 \text{ cm s}^{-1}$ ) in order to use the same amount of water (4 l). Both operations were separated by a hand-brushing step, as described above. Gutter areas were not suitable for the frame set-up: instead a 40-cm wide and 1-m long area was sampled. In order to avoid heterogeneity of collected samples, coarse solids  $> 4 \text{ mm}$  was discarded on all sites.

In order to avoid a too long sampling procedure which should have required car and pedestrian traffic interruption, the operation was conducted with four people: two persons for the vacuum equipment handling, one person for street brushing and one person for sample collection and vessel cleaning. It was necessary to carry the vacuum cleaner, the power supply and the necessary containers in a standard commercial vehicle. There was 25 bottles used for sample collection (4 l) initially filled with reverse osmosis water (after nitric acid cleaning procedure), three vessels for hydrocyclon (34 l), i.e. for road, gutter and footpath sampling, respectively, and a 20-l water tank for their cleaning between each sample collection.

#### 2.3.4. Street run-off water sampling

Sampling procedures for urban run-off within the 'Le Marais' experimental urban catchment have been previously described (Gromaire-Mertz et al., 1998a,b): during individual rain events, bulk samples were collected within three gullies (street run-off) and one combined sewer, at the catchment outlet. These bulk samples were immediately filtered for dissolved and particulate pollu-

tant determination. Whereas hydrocarbons were separately determined on both of these fractions, particulate metal concentration was calculated by subtracting dissolved metal levels from bulk concentrations (Garnaud et al., 1998).

### 2.3.5. Street deposit analysis

SS samples were sieved at 100  $\mu\text{m}$  on a Nylon mesh (Bioblock), and further filtrated on a 0.7- $\mu\text{m}$  GF/F Whatman membrane (pre-calcinated at 525°C during 2 h) for total suspended solid (TSS) determination after drying at 60°C and volatile suspended solid (VSS) determination after 2-h calcination at 525°C (Thermolyne, 48000).

Duplicate sieved samples were digested using 18 + 2 ml concentrated nitric–perchloric acid mixture (Merck Suprapure) added to 1 g dry wt. large particle (i.e. > 100  $\mu\text{m}$ , collected above the Nylon mesh) or 20-ml fine particle (i.e. < 100  $\mu\text{m}$ ) suspension. The 50-ml filtrate was acidified at pH 1 with nitric acid. Metal concentrations in digested sub-samples were determined by flame or electrothermic furnace atomic absorption spectrophotometry (AAS). Both particulate and dissolved sample digestion and quantification were validated using certified samples: NIST 1648 (urban particulate matter), BCR 146 R and 144 R (industrial and domestic sludge), NIST 1643 c (fresh water), SPS WW1 and SW2 (waste and surface water) (Promochem, Molshelm, France). Mean relative deviations from certified values were generally lower than 10% ( $n = 6-10$ ).

Dried fine particle samples were extracted in a Soxhlet apparatus over 24 h with a dichloro-methane–ethanol mixture (80:20 v/v). The solvent mixture was evaporated down to 5 ml under vacuum, and passed through a silica gel column for the separation of aliphatic and aromatic fractions. Both fractions were further evaporated down to approximately 250  $\mu\text{m}$  under nitrogen flux, and analysed by GC-MS (Hewlett Packard HP G 1800 A). Aliphatic and aromatic concentrations were determined using deuterated internal standards (*n*-C<sub>24</sub> D<sub>50</sub>, phenanthrene-D<sub>10</sub> and pyrene-D<sub>10</sub>, Euriso-top) (Estèbe et al., 1997) added into the Soxlet apparatus before extraction. PAH extraction and GC-MS quantification procedures were validated using a NIST 1941a marine sediment certified sample (NIST, Gaythersburg, USA) relative deviations as well as dispersion for triplicates were usually below 20%

## 3. Results and discussion

### 3.1. Validation of the sampling technique

Model sampling experiments performed with calcinated and sieved clay or gutter sediments deposited on the cleaned laboratory floor surface enable a clear discrimination between dry and wet vacuum cleaning procedures (Fig. 3). Although SS collection efficiencies reach 95% with dry sampling for 200–2000- $\mu\text{m}$  particles and sur-

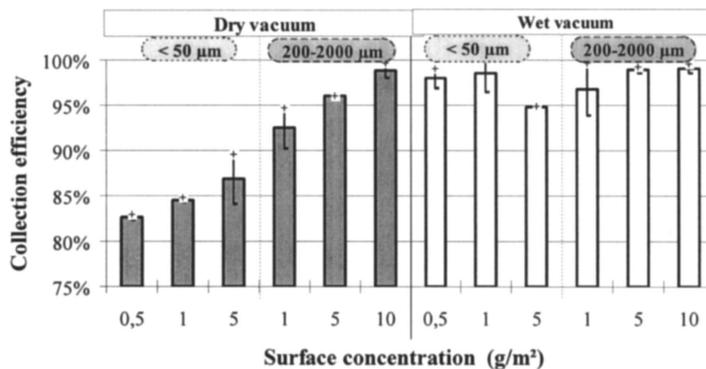


Fig. 3. Collection efficiencies of model experiments using dry (left diagram) or wet vacuum sampling (right one) and various surface concentrations of calcinated and sieved-clay (< 50  $\mu\text{m}$ ) or gutter sediments (200–2000  $\mu\text{m}$ ) deposited on the laboratory floor (see Fig. 1) : mean  $\pm$  dispersion of duplicates.

face loads larger than  $5 \text{ g m}^{-2}$ , wet vacuum collection efficiencies are always above 95% whatever the particle size and surface loads.

As the laboratory floor, although presenting approximately 3-mm wide and 1-mm deep cement junctions, is much smoother than the asphalt road surface, the wet vacuum sampling procedure was applied to the University car park area. The wet vacuum sampling allowed a collection of  $12.2 \text{ g dry wt. m}^{-2}$  for the first assay and 1.5, 1.1 and  $1.0 \text{ g dry wt. m}^{-2}$  for three successive assays on the same area: the sum of these four samples represent a surface load of  $15.9 \text{ g dry wt. m}^{-2}$ , which means that the first assay yielded only 80% of this sum. A similar wet assay was duplicated in another area of the same car park. The surface load obtained was  $10.0$  instead of  $12.2 \text{ g dry wt. m}^{-2}$  for the first step. A week later, the same car park was sampled for solid deposits, combining wet vacuum sampling and wet brushing. The surface loads obtained successively on the same area were 32.5, 9.3, 3.5 and  $2.7 \text{ g dry wt. m}^{-2}$ , respectively, the sum reaching  $48 \text{ g dry wt. m}^{-2}$ . This demonstrates the efficiency of the wet brushing both for the first assay (2.7 times larger surface loads) and for the sum of the four successive ones (three times larger), although the dry weather period before the experiment with brushing was very short ( $< 1$  vs. 7 days). When comparing the fine particles fraction, i.e.  $< 100 \mu\text{m}$ , 25.1 and  $5.4 \text{ g dry wt. m}^{-2}$  were obtained after four repetitions, either with or without hand brushing, while large particle collection was only doubled. This shows that the main effect of hand brushing is the mobilisation of finer particles. As such particles are usually described as more contaminated, it was decided to further use wet vacuum with wet brushing procedures. One should note that a 4-l injection, even coupled with hand brushing, is insufficient for a total urban deposit sampling on an asphalt surface. Successive amounts of dust collected after each step do not constitute a geometric sequence, which would mean that a constant fraction of a total dust residual on the surface is sampled at any step. The ratio between successively collected fractions ( $R_{m+1}/R_m$ ) increases with increasing step number. This result is understood as the occurrence of the easy collec-

tion of a limited amount of dust (mainly during the first step) followed by the more difficult collection of a large bulk of more strongly bound dust. The finer fraction appears more strongly bound to the asphalt surface than the coarser fraction, as long as the no-brushing technique is used, but the difference between both fractions becomes negligible as soon as the brushing technique is used. Brushing would therefore introduce less discrimination in sampling. Although the first sample represented only 70% of the surface load determined after four repetitions, it was decided to limit sampling to one set of 4-l water injection and brushing in order to obtain a larger number of samples per campaign for field work on a street of Paris centre.

### 3.2. Urban sampling in Paris centre: street dust surface loads

As particle surface loads present large spatial variability, it was not possible to differentiate between samples collected after one and five days dry weather periods. Footpath loads were much lower ( $1.6\text{--}3.8 \text{ g dry wt. m}^{-2}$ ,  $n = 6$ ) than road ( $8.5\text{--}17 \text{ g dry wt. m}^{-2}$ ,  $n = 6$ ) and especially gutter loads ( $17\text{--}144 \text{ g dry wt. m}^{-2}$ ,  $n = 6$ ). Organic matter content of particles, as assessed by their volatile suspended solid ratio (VSS) contents, i.e. their weight loss at  $550^\circ\text{C}$ , were not significantly different for footpath and road particles, i.e. 16–22 and 17–23%, respectively, with gutter sediments being somewhat less organic (7–16% VSS,  $n = 6$ ). This difference between footpath and road dust on the one hand and gutter sediments, on the other, is also evidenced by the difference in relative loads of particles larger than  $100 \mu\text{m}$ ; they reach 30–51, 22–37 and 41–76%, respectively for footpath, road and gutter particles. This result is probably related to the street cleaning procedures of this district of historical Paris: street hydrants are opened daily, for 0.5–1 h, and the finest sediments in gutters are transported to gullies.

Taking into account the respective widths of footpath (2.5 m), road (3.6 m for half width) and gutter (0.4 m) in Béarn Street, the average esti-

Table 1

Béarn Street deposit surface loads, metal contamination and metal surface loads: mean values obtained on 12 June 1997 ( $n = 6$ )

	Footpath	Gutter	1/2 Road	Total street	Gullies
Width (m)	2.5	0.4	3.6	13.0	–
Surface SS load ( $\text{g m}^{-2}$ )	3.3	40.5	10.2	9.4	–
<i>Cu</i>					
Conc. ( $\text{g kg}^{-1}$ )	0.69	0.20	0.15	0.36	0.46
Load ( $\text{mg m}^{-2}$ )	2.3	8.1	1.5	2.2	
<i>Pb</i>					
Conc. ( $\text{g kg}^{-1}$ )	2.9	3.3	1.2	2.0	1.7
Load ( $\text{mg m}^{-2}$ )	9.7	132.8	11.8	18.4	
<i>Zn</i>					
Conc. ( $\text{g kg}^{-1}$ )	4.3	2.0	2.0	2.9	3.9
Load ( $\text{mg m}^{-2}$ )	14.2	82.2	20.2	21.7	

mate for street surface concentration of solids reached  $9.4 \text{ g m}^{-2}$  (Table 1).

### 3.3. Urban sampling in Paris centre: metal and PAH concentration in street dust

Particles sampled during the 12 June and 19 June 1997 campaigns have been analysed for their metal and aromatic hydrocarbon (PAH) content.

Particulate metal concentrations present a large spatial variability (Fig. 4), the copper values being approximately one order of magnitude lower than lead and zinc. Taking into account the median, lower and upper deciles, it appears that footpath dust is much more concentrated in terms of copper than gutter and road samples; corrosion of copper-containing urban furniture and building may be a significant source of contamination (Table 1). As shown in Fig. 4, these street deposits appear to be as contaminated as particles sampled at any of the gullies within the 'Le Marais' experimental catchment (Fig. 2: 15 samples). Their contamination is also similar to those of dry fall-out particles sampled on the same site in 1996–1997, i.e. 0.8–2.9, 2.5–14.4 and 3.3–24.8  $\text{g kg}^{-1}$  dry wt. for copper, lead and zinc, respectively (lower-upper decile range,  $n = 28$ ) (Garnaud et al., 1998). Unlike the studies of Sansalone and Buchberger (1996), we observed similar or higher concentrations of copper and lead in the coarser

fraction ( $> 100 \mu\text{m}$ ) compared to the finer fraction, the concentrations were higher in the finer fraction only for zinc.

Based on average values of concentrations in solids collected at Paris, rue du Béarn, and at other urban sites where data have been collected, the centre of Paris appears to be severely polluted. Copper and zinc contamination are the highest among all reported urban deposit data. Taking into account the dust surface loads and

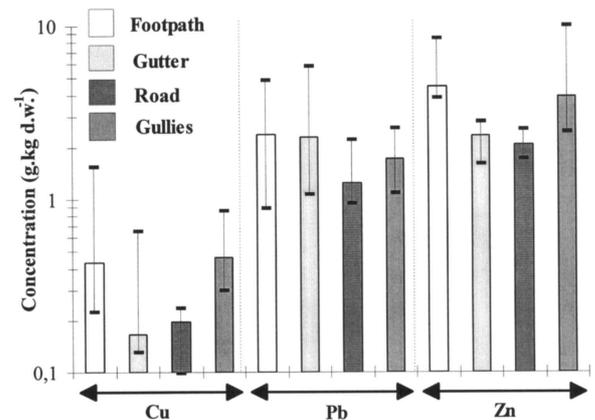


Fig. 4. Particulate metal concentrations in Béarn Street deposits: median and variation range ( $n = 7-8$ ) on 12 and 19 June 1997 samples collected on footpath, gutter and road. Comparison with median and deciles metal concentrations in particles sampled on three gullies within the experimental urban catchment (Fig. 2) in 1996–1997 ( $n = 15$ ).

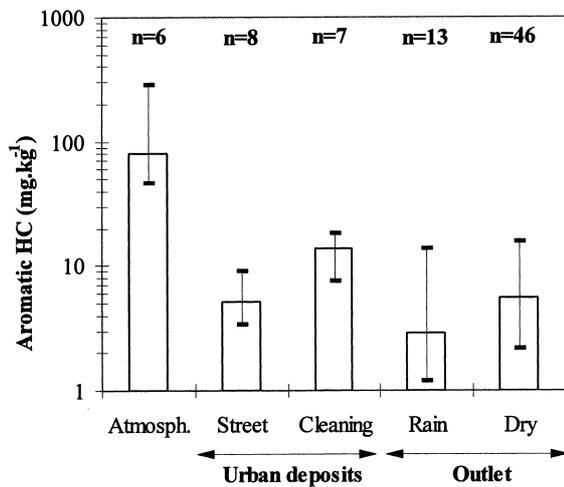


Fig. 5. Polyaromatic hydrocarbon (PAH) concentrations in particles sampled in dry atmospheric deposits (November 1996–March 1997), Béarn Street deposits or run-off during street cleaning procedures (12 and 19 June 1997), and catchment outlet during either wet (February–June 1997) or dry weather (January–April 1997): median values and deciles (number of samples).

their metal contamination, it appears that copper, lead and zinc surface loads are significantly higher at the gutter than on the road surface, with the latter values being higher than the footpath, except for zinc (Table 1, Fig. 7). These metal surface loads at footpath, gutter and road sites, enabled the assessment of the total Béarn Street load as being 2, 18 and 22 mg m<sup>-2</sup> copper, lead and zinc, respectively (Table 1).

Total PAH concentrations on particles deposited on streets appear to be significantly lower than those collected from dry atmospheric deposits (Fig. 5) but similar to those collected at the outlet of the 'Le Marais' urban catchment (Fig. 2) both during storm events and dry weather. This result shows that atmospheric deposits present a significant source of particulate PAHs in this urban catchment, apparently much higher than sources related to leakage from vehicles.

### 3.4. Street cleaning efficiency for SS and micropollutants

In order to assess the efficiency of the usual

street cleaning procedure, a procedure performed two to three times per week in the 'Le Marais' district of Paris centre, SS surface loads and their associated metal contamination were compared before and after the street water jet cleaning procedure commonly undertaken by workers from Paris city.

Although the spatial variability of SS surface concentration is large, the road values appeared significantly lower after the street cleaning procedure (Fig. 6). The removal efficiency was better for the road than for footpath and gutter and somewhat better for larger particles. Water entering gullies during street washing of a 29.5-m<sup>2</sup> area within Béarn Street was also collected and it was found to contain the equivalent of 3.5 ± 1 g m<sup>-2</sup> surface load (Dulac, 1997). Compared to our assessment of the total initial surface load of Béarn Street on 19 June 1997, i.e. 14.2 g m<sup>-2</sup> and to its value after the cleaning, i.e. 8.9 g m<sup>-2</sup>, it appears that a reasonable mass balance was obtained and that the water jet procedure used by Paris city workers removes approximately 25% of street deposits. As street run-off particles collected at gullies of this urban catchment during individual storm events represented a surface load in the 0.5–1.5 g m<sup>-2</sup> range (Dulac, 1997), rain events appear to transport only approximately 10% of the available street deposits and are clearly less efficient than water jet street cleaning. Such low cleaning efficiency values are probably even lower when the street cleaning is performed by Paris city street workers, who spend much less time and

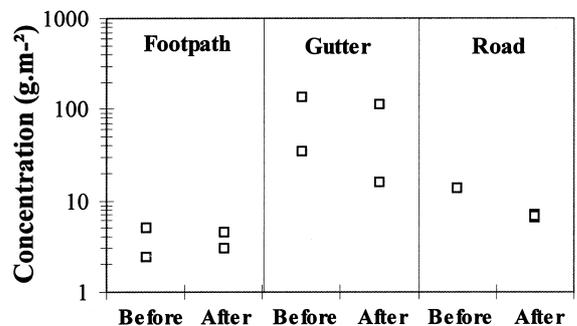


Fig. 6. Assessment of street cleaning efficiency on particle surface loads at Béarn Street (19 June 1997): comparison of bulk particles surface loads prior to and after street cleaning.

care on such operations.

Fig. 7 presents the metal surface load evolution during the water jet street cleaning procedure of Béarn Street. Although a large spatial variability was noted, metal removal was observed on footpath, gutter and road surfaces. The lower metal removals obtained for gutter sites are probably related to the high roughness of the gutter surface and to its very high SS surface loads. Furthermore, metal removal rates appear to be

somewhat larger for coarse particles, i.e. larger than 100  $\mu\text{m}$ .

#### 4. Conclusions

Based on model experiments performed with dry and sieved fine and coarse sediments, as well as on sampling in car park areas, it appears that the sampling method employed for urban dust and sediment plays an important role on the assessment of SS surface concentrations. A simple vacuum cleaning is less efficient, especially for fine particles, than suction of a suspension obtained with a local water jet; such a wet vacuum cleaning may be achieved with a commercial 'floor and carpet' vacuum cleaner. Wetting the finer particles improves their recovery inside the 'hydrocyclon' system; on the contrary, in the dry collector system, a fraction of the finer particles can easily cross the water-containing vessel and is not recovered. Furthermore, introduction of a brushing step improves, by a factor of approximately 3, the amount of solids collected on a given asphalt surface. Such brushing and suction procedure is clearly not complete since its replication on the same asphalt surface shows that only 70–80% is collected on the first step as compared to four replicates. This last result should be used with caution since it is clearly related to urban surface structure and roughness. Furthermore, a repetitive water jet and brushing procedure may contribute to the partial degradation of the asphalt surface and introduces a bias in the assessment of road dust surface concentration. Taking this into account, it was admitted that a good compromise for urban deposit sampling was the association of wet brushing and suction steps performed only once on a given area. Such a procedure allows a good discrimination between footpath, gutter and road surface loads. It can be performed, using an electric generator, on any street, although such sampling obviously necessitates deviation of the car and pedestrian traffic.

This sampling procedure allowed the assessment of street surface concentrations both in solids, metals (Table 1) or PAHs and the demonstration of a high mean contamination in copper

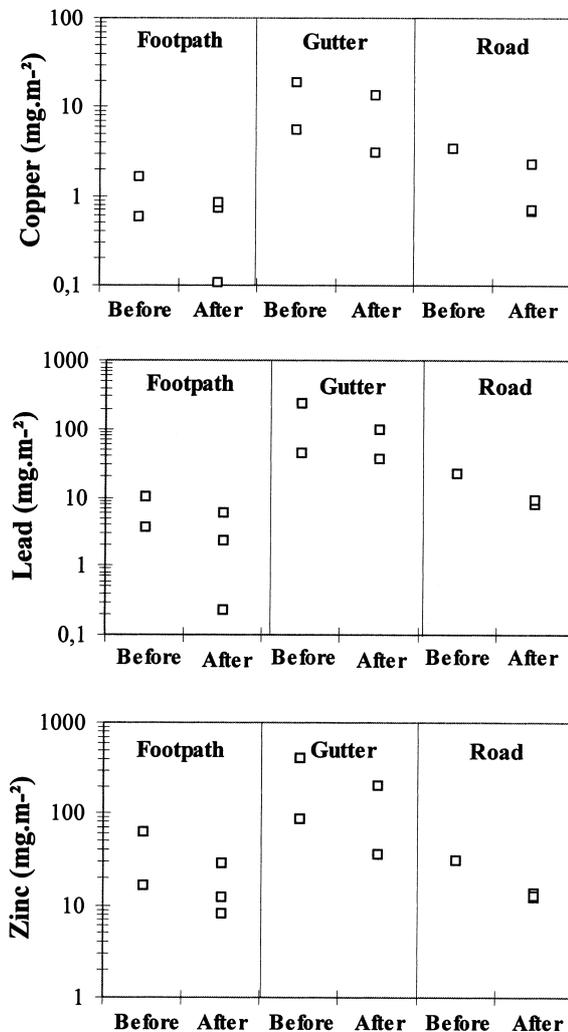


Fig. 7. Assessment of street cleaning efficiency on metal surface loads at Béarn Street (19 June 1997): comparison of bulk particulate copper, lead and zinc surface loads prior to and after street cleaning.

and zinc, as compared to other urban sites, reaching a mean value of 2.2 and 18 mg m<sup>-2</sup>, respectively. Within the studied street of this historical part of Paris centre, both of these metals may originate from the corrosion of urban furniture and local construction materials (Gromaire-Mertz et al., 1998b).

When used prior and after the street cleaning procedure, the sampling of street deposits allows a direct assessment of the cleaning efficiency. For example the water jet cleaning procedure was found to remove 20–65% SS but 0–75% metals and no significant PAHs: roughness of the street surface and granulometric distribution of micro-pollutants are clearly important factors for this removal. If the removal ratio of particles below 4 mm appears to be limited, it should be noted that, averaged on the whole street surface, the water jet removes a much larger amount than rain run-off, i.e. 25 and 10% of the total solids recovered by the wet vacuum sampling technique, respectively.

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