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Typology of roofing materials and evaluation of their pollutant potential

Typologie des matériaux de couverture et évaluation de leur potentiel polluant

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RESUME

A Paris, les eaux de ruissellement de toitures ont été identifiées comme contribuant largement aux fortes concentrations en éléments traces métalliques (ETM) dans les rejets urbains de temps de pluie. L'évaluation des flux d'ETM issus des toitures est donc nécessaire, tant à l'échelle du toit lui-même qu'à l'échelle, plus large, de la zone d'aménagement ou du bassin versant. Nos travaux ont débuté par une typologie des toits de la région Île de France, tant concernant les matériaux que leur mise en œuvre. Il apparaît alors que tous les types de toits sont susceptibles de relarguer des ETM. Une première modélisation des flux métalliques à l'échelle du toit a été testée. Les résultats, bien qu'encourageants, mettent en évidence un manque de données concernant les mécanismes et taux de relargage pour de nombreux matériaux. A l'échelle du bassin versant, un travail s'appuyant sur des banques de données urbaines existantes et des photographies aériennes BD Ortho de l'IGN et utilisant un logiciel de classification d'image nous a donné des résultats prometteurs quant à la classification automatique des types de toits.

ABSTRACT

In Paris, roof runoff waters have been identified for having a role in the high metallic concentration levels in urban waters. An accurate evaluation of metallic flows from roofs is thus needed, first at the roof scale and then at the catchment scale. We have begun this work with a typology of roofing materials in Paris and suburbs: kind of materials and implementation rules. It appears that all types of roofs are likely to present metallic elements. Then, a first attempt for modelling corrosion induced metallic emissions in roof runoff has been realized. The results were promising but they have underlined a lack of data concerning metal-runoff processes and rates for different materials. At the catchment scale, we have worked on Geographic Information Systems tools (especially urban data banks and air photographs from the National Institute of Geography), with an image classification software, and the results on a small catchment area are very promising concerning the automatic classification of roofs.

KEYWORDS

GIS tools; Heavy Metals; Metallic flows; Roof runoff waters; Roofing typology.

1 INTRODUCTION

Roofs are known for having an effect on the high metallic concentration levels in urban runoff waters. In central Paris, experiments revealed that metallic levels are largely higher in roof runoff waters than in streets or yards ones. For this urban context, it was established that this metallic flow was due to the atmospheric corrosion of metallic materials used for roofing and rainwater evacuation (Gromaire-Mertz et al, 1999).

Today, in the context of the European Water Directive (2000/60 CE), whose aim is to obtain a good ecological state of aquatic environments, it seems necessary to reduce the production of pollutants at their sources. Thus, major sources have to be identified and concerning metallic species, a better quantification of the emissions from roofs, in relation with the kind of material used is needed.

Indeed, a new research project called "TOITEAU" was started in 2005 by CERVE and CSTB, with the financial support of Seine Normandy Water Agency. The objective of this project is to develop a methodology to estimate metallic flows from roofs at two different scales: the roof and the catchment.

In this paper, we will report a review of the work already realized in this way, and describe succinctly what we are presently working on.

2 ROOFING MATERIALS IN PARIS AND SUBURBS

2.1 Market research

Roofing materials are divided in two mains groups: non-metallic ones and metallic ones. The non-metallic roofing materials include slates, terracotta and concrete tiles, concrete corrugated sheets, bituminous surfacing sheets for flat roofs but also lighting sheets in PVC, PE, PC, whereas the metallic roofing materials are large sheets in steels, zinc, aluminium, copper or lead, and some metallic tiles.

In the case of Marais catchment (42 ha), which is quite representative of central historical Paris, the proportion of the different roofing materials have been estimated (Gromaire-Mertz et al. 2002) to 54% of the zinc roofs, 22% of slate roofs, 20% of tiles and about 4% of flat roofs. These proportions of materials differ from one quarter of Paris to another, considering the period of urbanization: we can find from 50 to 75% of zinc roofing in the historical centre of Paris to less than 15% in the outlying districts built in the 1950's. It is important to notice that in central Paris, the situation is frozen due to architectural rules concerning historical monuments.

To evaluate market shares of materials in the rest of Paris conurbation, a market research of MSI Etude (France 2006), giving the number of m² sold in 2005 for each material, was used. In Table 1, we report data for "Île de France" (surface area of 50 to 80 km around Paris), and for France, in % of million m² sold in 2005, for construction and renovation.

Materials	Market share %		Total % (Île de France)		
	France	Île de France			
Non-metallic materials	Terracotta tiles	44.9	42.4	54.3	
	Concrete tiles	4.4	11.9		
	Natural slates	9.1	10.7	15.7	
	Asbestos cement slates	3.5	5.0		
	Others	15.4	8.4		
Metallic materials	Steels	17.7	12.8	21.1	
	Sheets	Zinc	2.7		6.2
		Aluminium	1.4		1.6
		Copper	0.4		0.4
		Lead	0.1		0.1
	Metallic tiles	0.4	0.5	0.5	

Table 1: roofing materials, market data from MSI Etude (France, 2006)

In our geographical context, tiles represent the principal material sold, with 54.3% of market share. Anyway, metallic sheets are largely present, with 21% of market share. The main metallic materials sold are in steels (12.8%), and zinc (6.2%).

The market of roofing materials is quite steady on the five last years. Île de France context appears to be somewhat different of the global situation in France. Indeed, if the main roofing elements sold are always tiles, the quantity of steel materials is about 30% lower in our context than in France, and on the contrary, zinc-based materials are about 2.5 times as represented as in France.

2.2 Typology of roofing techniques and materials

2.2.1 Methodology

On a roof, many elements can be in contact with rainwater: rake surface but also singular points (valleys, ridges,...) and rainwater evacuation elements (gutters, downspouts,...). All these elements and the usual materials used for them have to be identified and quantified in order to evaluate potential metal releases into the runoff waters.

In France, roofing techniques are described in details in reference documents (Documents Techniques Unifiés, DTU), addressed to professional roofers. Indeed, all roofing techniques are indexed, with the material they have to use and the way they have to implement it (DTU 40.1, 40.2, 40.3, 40.4, 40.5 and 43). All constructions are expected to respect these white papers. Thus, we have used these documents in order to evaluate surfaces of different metals used on each type of roof both for rake surface (including fixation elements) and singular elements (in m² per m² of rake surface for roofing material and fixation elements and in m² per linear meter for singular elements).

This analysis proved that all types of roofs, even in slates or in tiles, present many metallic elements, which could have a role in the metallic concentration level of runoff waters.

To give some examples:

- on slate roofs, eaves, valleys and ridges are in zinc; refraction points, ridges on walls and penetration elements (chimneys, roof window...) are in zinc and lead; and gutters and downspouts can be in zinc but also in copper,
- on tile roofs, all the tightness and evacuation elements are generally realized in zinc and lead.

The roof typology and the associated metal surfaces data tables established on the base of these white papers allows a quite good estimation of the metallic surface areas involved on a well-defined roof.

2.2.2 Examples

As an example, we will consider the block plan of a roof (figure 1), and we will imagine it either in tiles, or slates, or zinc, or lead, or aluminium or stainless steel. For each possibility, with the help of white papers, we have calculated the surface areas of Zn and Pb for each singular element of the roof.

On figure 1, the range of metallic surface areas is reported for the slate covered roof. In table 2, we report the length values of each singular element of our example roof.

Element	Ortho-Surface	Eave	Valley	Ridge	Chimney penetration
Length	185 m ²	60 m	3.6 m	38 m	3 m

Table 2: length of singular elements of our example roof

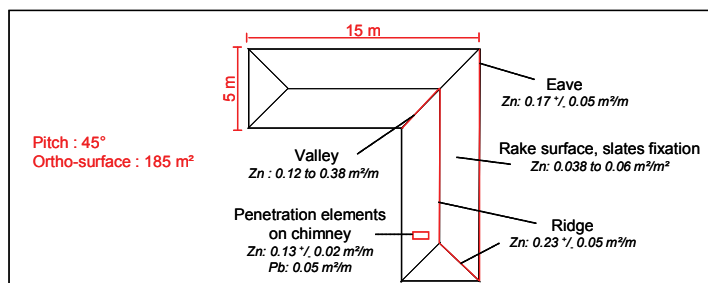


Figure 1: block plan of our example roof and metallic surface areas for the case of slate roofing

Table 3 summarizes the results of our estimations for zinc and lead surfaces, for the different materials we have chosen to study. For each value, we give a range with low, mean and high value.

We can notice that on tile roofs (which is the main material used for roofing in our geographical context), the surface area of zinc is important (about 10% of the surface area involved on the same roof covered with zinc). The surface area in lead is low, but on our example roof, we have only one chimney. It could be much more important in the presence of dormer windows, or others penetration elements.

Main material	Material of singular points	Zinc areas (m ²)			Lead areas (m ²)		
		low value	mean value	high value	low value	mean value	high value
Slates	Zinc and lead	21.8	29.3	36.8	0.1	0.2	0.3
Tiles	Zinc and lead	23.6	26.7	29.9	0.1	0.15	0.2
Zinc	Zinc	216.6	275.3	334.1	-	-	-
Lead	Lead and zinc	2.4	3	3.6	206.2	212.9	219.7

Table 3: Zn and Pb surface areas for different types of roofing

For aluminium and stainless steel roofs, singular elements are realized in the same material than the rake surface, in order to avoid some pits of corrosion at the interface between two metallic materials. Thus, the metallic areas involved are quite similar to those of the zinc roof but respectively in aluminium and in stainless steel.

3 ROOF SCALE: ATTEMPT FOR MODELLING CORROSION INDUCED METALLIC EMISSIONS IN ROOF RUNOFF

3.1 Idea and methodology

A model for the metallic roof runoff was developed, considering atmospheric conditions and roofs characteristics, based:

- on the typology of roofs and the quantification of metallic surface areas (1.2);
- on the Zn, Cu and Pb annual runoff rates found in the literature for atmospheric and pluviometric conditions similar to Paris (table 4). Cadmium emissions were estimated on the base on zinc ones, considering that cadmium is a zinc impurity (0.005% to 0.1% of Zn mass depending on production period, with an average of 0.05%)

If many studies concerning zinc and copper were found, only one was identified concerning lead and no one for the other materials behaviour (aluminium, steels...). Moreover, the literature reports much data concerning corrosion but few concerning

metal-runoff. These phenomena have to be distinguished: corrosion occurs at the interface between material and atmosphere whereas runoff occurs between patina and atmosphere. The value of runoff rate is a percentage of corrosion rate.

	Zinc			Copper		Lead
	Min.	Med.	Max.	Min.	Max.	1 value
Values (g. m⁻² yr⁻¹)	1.6	3.6	5.6	0.8	2	0.44
Reference	Odnevall Wallinder et al., 2004			Odnevall Wallinder et al., 1998		Schultze-Rettmer (1995)

Table 4: runoff rates given by literature

This model (one for each metal considered) was applied to the 11 roofs previously studied on Marais catchment (Gromaire-Mertz, 2001). These 11 roofs have been described in details, on the base of both on site inspections and cadastral plans.

The singular elements present on each roof and the materials used for it were defined from on site inspections. Based on the ground plan of the building, the map of the roof was designed with Autocad and the rake surface and the length of the different singular elements calculated. Areas of the different metals in contact with rainwater were then calculated using the typology data presented in 1.2 and annual runoff loads estimated.

Over the period 1996-1997, runoff waters from these 11 roofs had been sampled for 6 to 20 rain events and analysed for heavy metals. These experimental concentrations were extrapolated to an annual scale and compared to the results given by our model.

3.2 First results and conclusions

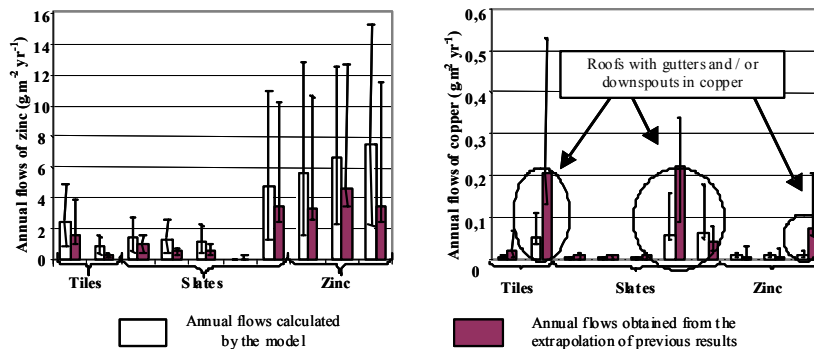


Figure 2: comparison of annual flows of zinc and copper calculated by the model on one hand and obtained by extrapolation of previous experimental results on the other hand.

Concerning zinc, the results of the two approaches were quite similar (figure 2): the model reproduces the variations from a roof to another. Nevertheless, we can notice that the median results obtained with the model are higher than those calculated from the experimental results (with a ratio of about 1.5), which probably means that zinc runoff rates given by the literature (table 4) have to be recalibrated for the case of Paris.

For copper, the results were more heterogeneous. In this case, the results given by the extrapolation of measured concentrations are higher than those given by the corrosion model (figure 2). The important differences observed for some roofs between the results of the two approaches can be explained by the fact that downspouts are in copper, and the corrosion model did not take into account the downspouts.

The results about cadmium were consistent but the ranges of the uncertainty are very high due to the lack of information about the production period of zinc present on our roofs, and consequently concerning the part of cadmium impurity in the materials.

Finally, the work about lead was not conclusive. The data given in literature are not detailed enough concerning lead runoff processes. It is necessary to realize specific experiments concerning lead behaviour in different atmospheric conditions.

This first approach for modelling metallic flows induced by roof runoff waters is promising. Anyway, it is clear that there is a real lack of information, especially concerning runoff rates of some materials, especially lead. Moreover, there are now many kinds of materials which are used as roofing materials (1.1) and the metallic species concerned by roof runoff are increasing every year.

4 CATCHMENT AREA SCALE: IMAGE CLASSIFICATION TOOLS

4.1 Needs and tools

The first need, in order to extrapolate our experimental data (at the test bed or roof scale) to the catchment area scale, is to evaluate ortho-surfaces of the different types of roofs. Thus, we have consulted urban data banks (cadastre), architects of "Bâtiments de France" and the French federation of buildings. These contacts showed that the information concerning the type of the roofing materials or the surfaces of different types of roofing materials on an urban district does not exist currently in urban data banks.

This is why, we have decided to focus our study on the characterization of roofs by using air photographs and classification software. By this way, we will not only determine ortho-surfaces of roofs but also identify roofing materials with their spectral signature.

After reviewing the different kinds of available images, we have decided to work with orthophotography (2004) from the French National Institute of Geography (IGN). These are air photographs, on which all the displacements due to land topography, axis of exposure or lens distortion have been corrected to obtain a photograph corresponding to a photographic map. These photographs have a resolution of 50 cm, and each pixel is defined by 3 channels (Red, Green, Blue or RGB).

An image classification software (Erdas Imagine) was used, which can treat classification, geographic information, land analysis, radar image...

To develop the method, we have chosen to work on the Marais catchment, for which we have many information and a good knowledge of the land use. Moreover, a manual estimation of roofs according to their materials has already been realized on this area in 1997.

4.2 Classification

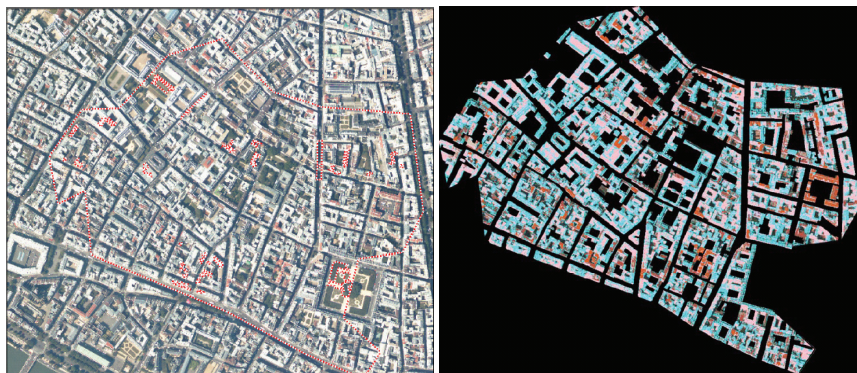
Classification consists in an image segmentation in different groups, characterized by their spectral signature. In our case, we have defined 5 main groups: roofs in zinc, slates, tiles, flat roofs and others (streets, yards...). We have created standard signatures representative of each group. Signatures are defined by the mean value of pixel for each RGB canal.

To quantify the results, statistics concerning percentages of points classed in each group in the area of interest are obtained, which allows the percentage of each type of roofing materials in this area to be estimated.

4.3 Image treatment and results

First of all, it is necessary to apply treatments to the raw image: definition of an area of interest (Marais catchment), application of a mask on the "non-roof" surfaces. This mask, which hides on the picture other urban surfaces than building, was constructed with the BD-Topo (IGN) which is a GIS topography database. First tests revealed the necessity to affine spectral signatures of materials. Indeed, the colour of materials depends of the age, the nature (terracotta tiles or concrete tiles), solar orientation... Thus, several signatures classes were created for each group of roofing materials.

Figures 3 and 4 present the image before and after treatments (definition of the area of interest, mask on "non-roof" areas) and classification (analysis of each pixel, and ordering in the corresponding spectral signature group).



Figures 3 and 4: orthophotography of Marais catchment before and after treatments and classification - blue, red and pink colours represent respectively slates, tiles and zinc roofs.

Results obtained with this automatic classification (figure 4), have been compared to the results obtained by the manual classification of roofing materials (for which the appreciation of the operator was taken in account). Table 5 reports the percentages values of each group, for the two classification methods.

Classification	Erdas (%)	Manual (%)	Error (%)
Zinc	54.17	54.61	-0.82
Slates	18.10	21.96	-17.58
Tiles	23.50	19.74	19.03
Flat roofs	4.24	3.87	9.43

Table 5: classification results and differences between the two methods

The difference between the two methods is lower than 20%, which is a tolerable error for this study. Anyway, a complementary work, both on standard signatures definition, by delisting some neighbours spectral signatures which can occur errors in the repartition in the different groups; and on the application of low-pass filter to the image, has been able to reduce this error to less than 10%.

5 CONCLUSION, ONGOING WORK AND PERSPECTIVES

The TOITEAU project has begun in 2005, with the aim of developing a methodology for the estimation of annual metallic flows from roofs at two different scales.

At the roof scale, a typology of roofing materials and techniques has been realized, in order to estimate metallic surface areas on each type of roof. This typology, coupled with runoff rates data found in literature, was on the base of a metallic runoff model at the roof scale.

It appears that the typology established permits a good evaluation of metallic surface areas for a roof, for which geometrical data the kind of materials used are well-defined. However, if we only know the type of the roof, the evaluation of metal surfaces is more difficult. In the case of a tile roof for instance, different materials can be used for singular elements. Thus, we intend to develop a statistical approach, coupled with the realisation of a regional survey with professional roofers, in order to acquire a good knowledge of usual techniques.

The results of the runoff model were promising but they clearly highlighted a lack of information concerning annual runoff rates of some materials in the atmospheric conditions of Paris conurbation. Thus, an evaluation of runoff rates from different materials exposed during one year in the atmospheric context of Paris is underway, as part of the TOITEAU project. Two experimental test beds have been constructed, permitting the evaluation of runoff rates of five families of materials; 3 types of Zinc, 3 Steels, 2 Copper, 2 Lead and 2 Aluminium products. These materials are tested as roofing panels 1250 x 400 mm (area 0.5 m²) but also as gutters (0.4 m long), fixation and tightness elements. The experimental design takes care of atmospheric parameters (two different sites corresponding to different values of atmospheric contamination in SO₂, in the range of Paris context have been chosen), exposures conditions (the effect of inclination and exposure direction is considered) and aging of material (both new and old material are tested). All the runoff waters are collected about every month (depending on the frequency of rain events) in polyethylene containers, acidified with nitric acid and analysed with ICP-AES technology. Runoff collection started in November 2006 and will last till the end of 2007.

Metal-runoff results from the test beds will be calibrated and validated at the scale of the roof, based on runoff sampling, over the same period of time, on several real roofs. We will thus appreciate the scale effect between test-beds and real roofs: differences in the hydraulic flow conditions on the two scales but also specificity of the flow in the evacuation elements.

For the evaluation of cadmium impurity, major zinc producers have been contacted, in order to define more precisely the evolution of refining techniques of zinc and the consequences on the cadmium impurity; and we have also planned to realize investigations to precise the age distribution of zinc-based roofs in Paris and suburbs.

At the catchment scale, a first test of automatic classification of roofs was realized, giving very promising results. This classification method will be improved, by defining others classes of materials in relation with their colours (old zinc, pre-patinated zinc...), but also by testing others automatic methods. Moreover, an evaluation method of length of singular elements with air-photographs will be developed. Indeed, if these evaluations are quite easy for gutters and ridges, it appears to be more difficult concerning dormer windows, valleys or eaves, which are not taken into account by 3D reconstruction models of urban land use from air and satellite photographs.

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