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Abstract: Roofing materials are considered as a major source of urban runoff contamination. Today, in the context of the European Water Directive (2000/60 CE), an accurate evaluation of contaminant flows from roofs is thus required at the city scale, and therefore the development of assessment tools is needed. However, at the city scale, the important diversity of roofing materials represents a difficult task for the quantification. In fact, the most restrictive step when estimating contaminant flows for large-scale territories is the estimation of the roofing materials surfaces area, for which no direct data exists. This study focuses on describing the method to evaluate gutter and valley lengths at the city scale. The proposed approach relies uses a statistical framework. The city was divided into homogenous urban areas. Then, a stratified random sampling technique was employed. The reliability of the methodology has been proved for three different urban areas (drained by sewer system) with known roofing materials distribution and known gutter and valley lengths. The obtained results show that a sample representing R=4% of the urban area leads to an absolute error less than 2% for gutter and valley length values.

Keywords: City scale, gutter, roofing material, statistical approach, valley

INTRODUCTION

Many studies developed since 1970 have highlighted the pollution from urban wet weather discharge and its negative impact on receiving water (Saget *et al.*, 1995; Ellis and Hvitved Jacobsen, 1996). Roofing materials are considered as a major source of urban runoff metal contamination received by sewer system. This observation was revealed by several research programs conducted since the 1990s (Förster, 1996; Odnevall Wallinder *et al.*, 1998; Gromaire-Mertz *et al.*, 1999). In this context, annual metallic runoff rates at different scales (test-bed and roof) have been evaluated, for the different roofing materials commonly used in Paris and suburbs (Robert-Sainte, 2009). Further undergoing research aims at extending runoff rates at the city scale (Robert-Sainte, 2009; Gromaire *et al.*, 2011). The roof area estimation is a fundamental input for evaluating roofing materials emissions. However, at the city scale, the information concerning roofing materials and their surfaces on an urban district does not exist currently in urban data banks. Some methods (Gromaire *et al.*, 2002; Le Bris and Robert-Sainte, 2009) have evaluated roofing materials surfaces using data obtained from aerial photographs and image classification software. This classification method based on aerial images was applied to an urban catchment with 2.25 km² of surface. This method allows only identifying and quantifying roof area. For the other element of roof (ex: gutter and valley), no method has been found to identify and evaluate their materials surfaces.

In this work, a methodology is developed to quantify gutter and valley lengths at the city scale. The method is based on a statistical approach and is applied to Créteil city (France). The data are processed with the aid of a Geographical Information System (QGIS) and Matlab is used to implement the statistical approach.

METHODOLOGY

Case study site

The selected city is Créteil (Department 94) located about 10 km from Paris (France). Créteil has 89 304 inhabitants (INSEE, 2008) distributed over 11.5 km². Créteil city presents a big diversity and a large number of buildings which represent about 54% of the city area.

In a previous work, we have developed a set of rules for identifying the use of a roofing material at the city scale. These rules have been applied to Créteil city. In this work, we have combined different databases for Créteil: land use database MOS-IAU[1], images database BD-topo[2] and BD-ortho[3]. The obtained results correspond to two maps of Créteil city (see Figure 1). The first map represents the roofing material historical distribution (see Figure 1.a). Each color represents an area with the same material historical distribution. The second one is a building classes map (see Figure 2.b) established from reorganizing the MOS-IAU database. Each color represents a building class.

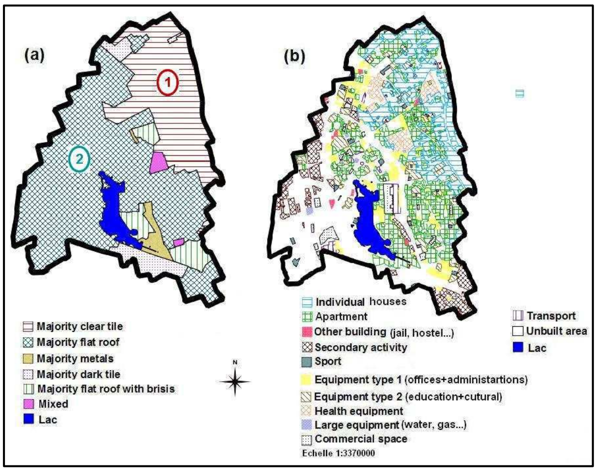

Figure 1 : (a) Material distribution map (b) Building classes map

Method for gutter and valley lengths estimation and application to Créteil

Given the size of the city, a complete census of the roofing material surfaces was unfeasible. In a previous work (Sellami-Kaaniche *et al.*, 2013, submitted), we have developed a statistical approach to evaluate roofing material area distribution at the city scale. This method was based on a stratified random sampling technique which was employed in conjunction with aerial photograph interpretation of surface roofing materials types (ex: zinc, tile).

The city was divided into distinctive homogenous strata in order to accurately characterize it. The homogenous strata are obtained by overlaying the two previous maps (Figure 1). In fact, we consider that each building class in figure 1.b located in an area of the figure 1.a is a homogeneous urban area in terms of building types and the historical location. We define homogeneous urban area as an area representing specific probabilities of roofing material distribution.

The statistical approach to evaluate roofing materials distribution for a stratum (roofs area *(N (m²))* was based on two steps. The first one is the sampling theory which aims to determine the number of samples required n_r for all roofing materials. The second step is the application of the estimation theory. Indeed, after determining the number of samples n_r, we determine the proportion $R = n_r/N$ and then we estimate the unknown characteristics of a stratum by generating a sample representing *R (%)* from the total area of the new stratum. To validate this proportion *R* we have tested three stratums with different characteristics. The obtained results have shown that a random sample representing *R=4%* of the zone area could be draw

[1] IAU: institute of planning and development for the Greater Paris region (http://www.iaurif.org)
[2] BD-Topo is a database for Topographic Information IGN made from an aerial image. These images define only the built by masking inbuilt areas
[3] BD-ortho images come from IGN's (Institut Géographique National) which contains digital colour ortho-photos with a 50 cm ground resolution.

with or without replacement. Then, the estimated roofing material distribution of the zone will be established by applying theorem for proportions. Thus, we will obtain an estimation of each roofing material proportion by computing the confidence interval. This statistical method will be applied to quantify gutter and valley lengths. We propose to evaluate gutter and valley lengths for each roofing material type.

The sampling strategy is based on randomly generating independent individuals of 1 m² representing 4% of the stratum roofs area *(N (m²))*. Each 1 m² belongs to a specific building with specific roofing material. So, we obtain two databases, the first one is a database of different buildings (with their roof surface *($S_{r,b}$ (m²)*) existing in the stratum, and the second one is composed of the selected surfaces for each building *($S_{s,b}$ (m²))* in the sample. By associating BD-topo and BD-ortho we can measure with QGIS the length of valley *($l_{v,b}$ (m))* and gutter *($l_{g,b}$ (m))* for each building and also identify its roofing material. For each 1 m² of roof surface *($S_{r,b}$ (m²),)* we associate x_r *(m)* of gutter length and y_r *(m)* of valley length selected in each building. Then, in the sample, the length of gutter *($l_{g,s}$ (m))* and valley *($l_{v,s}$ (m))* will be evaluated as follow:

$$x_{\mathrm{r}} = \frac{l_{g,b}}{S_{r,b}} \; ; \quad \mathrm{l}_{\mathrm{g,s}} = x_r \times S_{s,b} \; ; \qquad \mathrm{y}_{\mathrm{r}} = \frac{l_{v,b}}{S_{r,b}} \; ; \quad \mathrm{l}_{\mathrm{v,s}} = y_r \times S_{s,b}$$

Finally, we compute for each material *i*:

- in the stratum: (area *(N (m²))*, proportion of different existing materials *(p_i (%))*, surface area of each material *i (S_i)*, the real gutter length $l_{g,i}$ *(m)* and the real valley length $l_{v,i}$ *(m)*
- in the sample representing 4% of the stratum area *(N)* : surface area of each material *i ($S_{s,i}$)*, gutter length $l_{g,s,i}$ *(m)* and valley length $l_{v,s,i}$ *(m)*.

RESULTS

The method of evaluating gutter and valley lengths at the city scale was applied and validated for three strata with known and different characteristics. The three tested strata are described as follows:

-Zone1 (*N_1=6256.84 m²*): individual house class (Figure 1.b) located in area (1) (Figure 1.a).
-Zone2 (*N_2=81100.11 m²):* apartment class (Figure1.b) located in area (2) (Figure1.a)
-Zone3 (*N_3=105304.04 m²):* secondary activity class (Figure 1.b) located in area (2) (Figure1.a)

Uncertainty in the gutter and valley lengths evaluation

Results obtained (see table1) in each sample have been compared to the real values in each stratum by computing an absolute error ($E_{a,g}$ and $E_{a,v}$). This latter is the difference between $R_{g,r,i}$ real ratio and $R_{g,s,i}$ ratio in the sample for gutter length and the difference between $R_{v,r,i}$ real ratio and $R_{v,s,i}$ ratio in the sample for valley length.

$$\mathrm{R}_{\mathrm{g,r,i}} = \frac{l_{g,i}}{S_i} \times 100 \; ; \quad \mathrm{R}_{\mathrm{g,s,i}} = \frac{l_{g,s,i}}{S_{s,i}} \times 100 \; ; \quad \mathrm{R}_{\mathrm{v,r,i}} = \frac{l_{v,i}}{S_i} \times 100 \; ; \quad \mathrm{R}_{\mathrm{v,s,i}} = \frac{l_{v,s,i}}{S_{s,i}} \times 100$$

$$E_{\mathrm{a,g}} = \mathrm{R}_{\mathrm{g,r,i}} - \mathrm{R}_{\mathrm{g,s,i}} \; ; \qquad E_{\mathrm{a,v}} = \mathrm{R}_{\mathrm{v,r,i}} - \mathrm{R}_{\mathrm{v,s,i}}$$

Table 1 : Absolute errors values computed for each material and for the three zones

	Zone 1			Zone 2			Zone 3		
Material	**Proportion p_i (%)**	**$E_{a,g}$ (%)**	**$E_{v,n}$ (%)**	**Proportion p_i (%)**	**$E_{a,g}$ (%)**	**$E_{v,n}$ (%)**	**Proportion p_i (%)**	**$E_{a,g}$ (%)**	**$E_{v,n}$ (%)**
Clear tile	33,7	0.51	1.55	x	x	x	x	x	x
Dark tile	19,6	0.44	0.31	5,6	0.08	0.00	x	x	x
Slates	14,2	1.25	2	1,2	1.73	0.04	x	x	x
Zinc	13,3	0.98	0.50	x	x	x	1,1	0.46	0.00
Flat roof	15,7	0.00	0.00	91,9	0.00	0.00	86,5	0.00	0.00
Steel	1,9	0.00	0.80	0,7	0.01	1.03	8,8	0.17	0.00
Other material	1,6	0.00	0.13	0,6	0.99	0.60	3,6	0.28	0.00

Table 1 shows that for the three zones the absolute error for the gutter and valley lengths is less than 2%. Therefore, the developed method ensures good results in computing gutter and valley lengths at the city scale.

CONCLUSION AND PERSPECTIVES

A method was proposed and applied to Créteil city to evaluate roofing material distribution and the gutter and valley lengths. The new question is “How to apply this method to other cities?”

Therefore, the first step is to divide the city into fairly homogenous urban areas by overlying two types of maps as illustrated in figure 1 for Créteil. The first map represents the roofing material historical distribution. This map should be elaborated for the case study city. To this end, we need an historical evolution of the city urbanization. This type of map can be available in the town halls databases or in the libraries of municipalities, etc. Besides, it is important to identify the different existing rules in the city related to the use of roofing materials such as the town planning regulation framework and the Local Urbanism Plan document.

For the Ile-de-France cities, the building class databases are the same as Créteil. Elsewhere, land use database are available but present some differences versus MOS-IAU that should be take into account to obtain the different established building classes.

The second step of the method is to apply the statistical approach. In fact, for each homogenous urban area (with known surface), a sample representing $R=4\%$ of the area surface is randomly generated. After that, using GIS software, we associate for each sample different maps BD-topo, BD-ortho and the strata one to identify the roofing material, the gutter and the valley lengths. Finally, we obtain the roofing material proportions, gutter and the valley lengths for each material type.

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