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EVALUATION METHOD OF THE LOADS OF POLLUTANTS TRAPPED IN THE INFILTRATION BASIN AND THE ESTIMATE OF ITS EVOLUTION.

MÉTODO PARA LA EVALUACIÓN DE CARGAS DE CONTAMINANTES RETENIDOS EN CUENCAS DE INFILTRACIÓN Y ESTIMACIÓN DE SU EVOLUCIÓN

Wolfield Tingué[1 2], Marie Gisèle P.A. Pierre[1,3], Sylvie Barraud[2]

Abstract

The techniques of rainwater infiltration in urban environment tend to reduce the debits and/or the rain waters, and also limit the phenomena of washing urban surfaces by streaming waters and so, allow reducing their polluting loads. However, the potential of transfer of the pollutants contained in these waters represents a threat for the quality of the underlying grounds and underground waters. The objective of infiltration basins is also to retain the polluting load contained in these kinds of water and set it up so that the effluent that leaves the basin does not have any negative impact on the natural environment. Therefore, the durability or effectiveness of these systems of infiltration in long term must be studied. Indeed, the goal of this study is to propose a method of characterization of the spatial heterogeneity from the concentrations in heavy metals measured in the basin of Django Reinhardt if, annually based, the concentrating pollutants or their distribution evolved. Three campaigns of measurement have been realized one year apart. The first one in April 2005 reached 103 points; 92 points for the second one in February 2006; and 99 points for the last in July 2007. The analyzed parameters for each sample are: the Lead (Pb), the Copper (Cu), Zinc (Zn) and water content (W). The method used for the characterization was the Krigeage. Analyses based on a sample of 5 cm of studied grounds show that the basin is polluted to the surface. They revealed as well an accumulation of pollutants among the three campaigns, especially at the entrance of the basin and, in the oldest part compared the rest of the system. At last, a report of total mass of heavy metals trapped in the basin was restored on the 5 cm of studied grounds.

Key Words: Infiltration Basin, Heavy Metals, Effectiveness, Spatial Heterogeneity, Krigeage.

Resumen

Las técnicas de infiltración de las aguas pluviales en medio urbano se encaminan a disminuir los caudales y/o los volúmenes de aguas pluviales. Limitan al mismo tiempo los fenómenos de colada de las superficies urbanas por las escorrentías, y permiten pues disminuir sus cargas contaminantes. Sin embargo, el traslado potencial de los contaminantes contenidos en esas aguas constituye una amenaza para la calidad de los suelos subyacentes y aguas subterráneas. El objetivo de las cuencas de infiltración consiste también en retener la carga contaminante contenida en esas aguas y de fijarla para que el efluente que deja la cuenca no tenga ningún impacto negativo en el medio natural. Por lo tanto, la durabilidad o la eficacia de esos sistemas de infiltración a largo plazo debe estudiarse. El objetivo de este estudio es proponer un método de caracterización de la heterogeneidad espacial, a partir de concentraciones en metales pesados medidas en la cuenca Django Reinhardt si, a escala anual, las concentraciones en contaminantes, o su repartición, han progresado. Tres campañas medidas han sido realizadas a intervalos de un año: la primera, en abril de 2005, cuenta con 103 puntos; la segunda, en febrero de 2006, agrupa 92 puntos y el último, en julio de 2007, reúne 99 puntos. Los parámetros analizados para cada muestra son: el plomo (Pb), el cobre (Cu), el cinc (Zn) y el contenido en agua (W). El método de caracterización utilizado fue el Krigeage. Los análisis muestran sobre los 5 cm de suelos estudiados que la cuenca está contaminada a la superficie. También permitieron detectar una acumulación de los contaminantes entre las tres campañas, sobre todo a la entrada de la cuenca y en la parte más antigua que el resto del sistema. Por fin, sobre los 5 cm de suelos estudiados un balance de masa total de metales pesados prendidos en la cuenca se reconstituyó.

Palabras clave: Cuenca de infiltración, Metales pesados, Eficacia, Heterogeneidad espacial, Krigeage.

INTRODUCTION

Within the space of a few years, water is become one of the major issues of the 21st century and, the durability of its protection and management is at the heart of political discussions. The classical techniques – developed since 19th century – have been thrown back into doubt while the research of new solution which can protect better the environment and the resources is a worldwide concern today (Chocat et

1 Laboratoire d’Analyse des Matériaux (LAM), BP 796 Université Quisqueya, Port-au-Prince, Haïti. e-mail: wolffy_22@yahoo.fr

2 Laboratoire Génie Civil & Ingénierie Environnementale (LGCIE), INSA de Lyon, Bâtiment Coulomb, 20, Avenue A. Einstein 69621 Villeurbanne Cedex, France.

3 Association Haïtienne Femmes Science et Technologie, Université Quisqueya, Port-au-Prince, Haïti.

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al., 2004). This phenomenon is particularly true today for the management of rain waters whose techniques are alternative, and more particularly the techniques of infiltration introduce new issues and technologies to cope with it. So, the infiltration basins must be considered in the management of rain waters (Boller, 2004).

For thirty years, the infiltration basins of rain waters are become a common way of cleaning up gathering flows of water is towns and decrease the pollutants in natural zones (Nightingale, 1987; Yousef et *al.*, 1994). However many questions remain about their aptitude to bring a long-lasting help (economic, technique, social and environmental). The environmental dimension linked to the preservation of natural environment in particular: protection of the ground waters and the soils against diverse forms of pollution linked to rain waters (Dechesne, 2002). These methods of rain waters management are often qualified as those environmentally suitable (Lind et Karro, 1995); for, they contribute to the reduction of high rate of flows and the volume of streaming. They also allow reducing the frequency of floods and contributing to the quantitative recharging of the ground waters. Those techniques contrast with the principle of unit channel (Chocat, 1997). The infiltration zone made up of a retaining basin and an infiltration basin lie in urban landscape (Fischer *et al.*, 2003; Dechesne et *al.,* 2004). They have great potentialities, considering the form and the possibilities of various uses facilitating them to integrate the social fabric.

The infiltration basins can impact the receiving environment that is the soil and the ground water (Dechesne, 2002). The pollution of underground waters is very critical the fact that the ground waters represent an important source of mineral water (Brelot, 1994). By infiltrating, the pollutants contained in rain waters are to a large extent in the soil (Lind and Karro, 1995) and the knowledge of their future remains unsatisfied.

The quality of rain waters infiltration is very variable from one rainy season to another; from one fluvial basin to another (Bardin *et al.,* 2001; Forster, 1990, 1996, 1999; Person *et al.*, 1993; Thevenot, 1992). That's understandable by the fact that streaming waters loaded first in contact with atmospheric pollutants, then, on the impermeable surfaces catching in this way organic and mineral pollutants. So rain waters can carry great quantities of various pollutants: heavy metals, hydrocarbon, pesticide, and bacterium, nutritive elements, in the form of dissolved or particle. This pollution focuses, to a large extent on solid particles (Bachoc *et al.,* 1992).

Lind and Karro, 1995, revealed that the concentrations of heavy metals in the soils of infiltration zones are twice the quantity of those in reference[1] zones. According to Makepeace and al., 1995, the concerns of heavy metals in today's world focus on: the lead, the cadmium, the copper and zinc, since those metals represent a considerable part of pollutant in rain waters. This study on the Django Reinhardt's basin, infiltrating on surface of 8000 m² the water of a fluvial basin of 185 ha study particularly the concentration of heavy metals found in the basin. Three campaigns of measure have been made on the site and each of them has the heavy metals analysis by spectrometric of fluorescence X portable on 100 points, 92 points, 99 points distributed on the surface of the infiltration basin. To assess the environmental quantity, indicators have been suggested. What must be done now it's to assess the quantity of pollutants bring to the work and those trapped particularly by the work–soil interface.

METHODOLOGY

Django Reinhardt's experimental site

The infiltration basin of Django Reinhardt is located in the East plain of Lyon and the subjacent soil is made of fluvial and icy alluvia very permeable. It was built in 1975 to collect rain waters of the industrial area of Chassieu. The surface of the fluvial basin is around 185 ha. Its topography is flat (slope of 0,004) and the system allows rain waters and cooling waters taken to be clean. The subjacent soil is made of fluvial and icy alluvia very permeable. To sum up the ground water is deep (around 13 m).

This site which is use for 20 years, from the start, included three compartments (figure 1). It has been renovated in 1975, 2002 and 2004. The main objective of this development was to increase the capacity of the retention basin and merge the two other basins in an infiltration one. It's made up of two under basins linked together with pipe of 60 cm of diameter: an under basin of stocking-decanting, in which the water comes first to arrive in an infiltration under basin (Bardin and Barraud, 2004).

The stocking under-basin has a watertight verge by a geomembrane. It has a capacity of 32200 m^3 on ground of 11302 m². The water comes in the basin through two circle collector of 1.6 m of diameter and the emptying of the retaining basin is done by a surverse and a flow regulator of L/s (Bardin and Barraud, 2004).

After three years of use, the infiltration compartment appears quite plugged off. And the most plausible hypothesis of that phenomenon is an insufficient decantation in the retaining basin (Bardin and Barraud, 2004). On Badin and Barraud (2004) recommendation, the under basin of retaining-decantation has been modified. This modification has made to built a low wall in order to separate the under basin so as to facilitate the decantation.

This study realized on this site highlights a casual conjunction. The first one is linked to the behavior of the retaining basin that does not ensure a satisfied decanting as mentioned before. Indeed, the first

1 Similar zones not having served to the infiltration

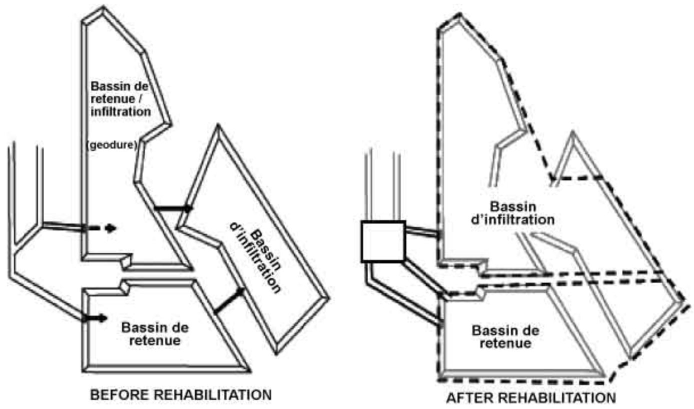

Figure 1. Diagram of the system before and after rehabilitation

compartment of retention was conceived for hydraulic use and not decanting use.

The second cause is linked to waters of dry season pouring into the system. We periodically remark suspicious pollutants contained hydrocarbons which have nothing to do with cooling waters.

The third cause is linked to the execution of the works. The cleaning out of the system seems not to be done correctly. The first signs of plugging could be seen quickly in the zone corresponds to the former infiltration basin. The easiness with which the basin is plugged all over the surface, while the zone corresponds to the former emergency basin didn't show any sign of plugging, indicates that sediments of the former infiltration site would have been spread on the current infiltration basin, and at the time of carrying out excavation works.

Study data

Three campaigns of measure have been realized on the Django Reinhardt site at Chassieu. The first one took place in April 2005, the second on in February 2006 and the last in July 2007. The Niton measures results have been adjusted by straight lines found from a few samples and their concentration measured by the Niton and by ICP-MS. Each of these measures have the analysis of heavy metals by spectrometry of fluorescence X portable on 103 points for the first sample, on 92 points for the second and 99 for the last. All of them are equally spread on the infiltration basin surface at around 7000 m². The parameters analyzed for each sample are the concentration in Pb, Cu and Zn (mg/Kg), so as the water level W (%). Those points are spread on the whole surface of the basin in accordance with a grid of 10 m × 10 m.

Figure 2: Samples of taken soils (Infiltration basin of Django Reinhardt in Chassieu, July 2007)

The samples of the soil (figure 2) have been taken with shovel on about 5 cm of depths. The extrinsic characteristics of the soil samples taken are different from one point to another. A few of them have many vegetables extracts relatively thin and, others are much more ochre and must contain fluvial ice, there are a few of them that have been taken out of water that contains a lot of fines.

The three campaigns have been realized one year apart, so much so that it will be possible to study annually the concentration of pollutants or their distribution evolved.

Analysis and characterization methods (geostatistic methodology)

Geostatistic analysis tool

The program **R**, 2006, "**geostatistic analysis tool**" has been chosen to assess and compare the heavy metal pollution level found in the soil of that basin for the three sampling campaigns. R is at once software and a qualified language of the S dialect created by AT&T Bell Laboratories.

Hypothesis analysis

In this study, the deterministic methods have been put aside to be replaced by the stochastic ones which suggest a probabilistic model to formalize the behavior of physical phenomenon under consideration. Given the Krigeage takes in consideration the spatial dependence structure of the data seems to be the most reliable to quantify the pollutants. The basis idea of the Krigeage is to forecast the regional variable values. In general, the method has 5 steps:

1. Exploratory analysis (i.e. the data visualization) allows oneself to familiarize with the data and determine the choice of the model.
2. The analysis called variographic, that is, the variogram assess, allow to quantify the spatial variability of the pollutant from the values analyzed in different selective sites of measure and according to the distance among them. The exponential model was chosen to realize the variogram. To write a model with naked eye, we need to add value to the level, at the nugget effect level. At last, two models of semi-variance must be adjusted according to the distance and initialize the level values of the level and the nugget effect.
3. The type of Krigeage choice. In this research work the choice is settled on the ordinary Krigeage on a regular model, called selective Krigeage. This type of Krigeage allows to create a regular grid on a given domain and Krigeage on each point of the grid. It allows observing the Krigeage values and errors variance. Interpolation grid of (100000, 100000) was chosen and according to topographic statement that identify 144146 point on the whole basin surface of 8277,22 m² was obtained with Autocad. This surface allows forming the boundary of the basin or the interpolation zone by Krigeage.
4. The achievement of interpolation by ordinary Krigeage.
5. The assessment of the model accuracy and of the quality mostly by a cross validation.

Pollutants mass assessment

The pollutant mass for each point is calculated up by the following equation:

$$m_i = \rho . s_i . (f . e_i . c_i)$$

With:

m_i : Pollutant mass for each point

f : This portion of the layer of surface, f = 25%

ρ: Volume (mass) of the soil, ρ= 2600 Kg/m^3

e_i : Depth of the layer of the soil taken on surface, e_i = 5 cm

s_i : Stitch surface i

c_i : Pollutant concentration in the stitch i

The surface used to determine the pollutant mass valuation is the influence surface by point. To calculate this surface, we divide the total surface of the basin which is 8277, 22 m² by the number of points of the topographic statement which are 144146 in numbers. The pollutants volume is calculated with the depths of the soil layer taken as sample, that's the 5 cm surface layer. The total volume of pollutants is calculated by adding the volumes in each point. The concentrations used are the calculations are the measured valuation on the Django Reinhardt site minus the ones of the reference soil (table 1).

Table 1. Pollutants concentration in the reference soil

	Pb (mg/kg)	Cu (mg/kg)	Zn (mg/kg)
Reference soil (Winiarski et *al.,* 2001)	6	6	46

RESULTS AND DISCUSSION

The results obtained and their interpretation for the spatial and temporal progress of heavy metals concentration (Pb, Zn, Cu) are presented in this part:

Statistic data for the three campaigns (April 2005, February 2006 and July 2007

The average concentration (mg/kg), the median (mg/kg) and the variation coefficient (Cv %) of concentration for each campaign are presented in the tables 2, 3 and 4.

In 2005 (table 2), the average concentration of Lead and Zinc are lower than the values guides (VDSS and VCI) in terms of soils pollution (BRGM, 2000). Consequently those values are not very dangerous for the soil. On the contrary, the average value found for the Copper a greater then the VDSS minimum guide values.

Table 2. Statistical data (April, 2005)

	April 2005 (N=103)		
	Pb	Zn	Cu
Average	63	833	110
Median	47	568	75
standard deviation	43	758	96
Cv (%)	68	91	87

In 2006 (table 3) the average concentration for the Lead and Zinc compared to the guide value are not dangerous for the soil. The Copper remain the same as it was in 2005.

Table 3. Statistical data (February, 2006)

	February 2006 (N=92)		
	Pb	Zn	Cu
Average	188	1135	177
Median	131	1133	190
standard deviation	194	734	107
Cv (%)	103	65	60

At last, for year 2007 (table 4), the average concentration of Lead and Copper is a potential risk of source of pollution compared to the under soil values definition (VDSS). But the average concentration of Zinc is not.

Table 4. Statistical data (July, 2007)

	July 2007 (N=99)		
	Pb	Zn	Cu
Average	234	1299	213
Median	221	1268	220
standard deviation	87	474	72
Cv (%)	37	36	34

Correlation between the parameters

The study of the correlation between the parameters can show that the metal form dynamic in the sampling soils depends on the physico-chemical characteristics. Because of this, the different metals of the first campaign (table 5) have a good correlation among them. They are almost linear, that is (r=1). For the second and the third as well (table 5), the correlation among the different metals are much weaker compared to the first campaign. It seems that the different metals do not have the same behavior. In addition, the correlation from one campaign to another (table 6) seems to be very weak for the different scenarios.

Table 5. Correlation coefficient between the pollutants for the three campaigns

	Correlation coefficient : r		
	April 2005	February 2006	July 2007
Pb/Zn	0,94	0,30	0,34
Pb/Cu	0,95	0,54	0,58
Zn/Cu	0,86	0,80	0,77

Table 6. Correlation coefficient from one campaign to another

	Pb/Pb	Cu/Cu	Zn/Zn
1st and 2nd campaign : r	0,12	0,30	0,49
1st and 3th campaign : r	-0,22	0,22	0,44
2nd and 3th campaign : r	0,36	0,41	0,56

Heterogeneity spatial analysis (pollutants content)

The pollution evolution on the time gives the following results:

For the Lead

In 2005, the concentrations in **Lead** (table 7 and figure 3) are distributed in the whole basin, but the most concentration is found in the former part of the basin.

In 2006, the pollution distribution of **Lead** could be shown at the entrance of the basin and in the rest of the basin this pollution is relatively constant.

In 2007, a strong pollution of **Lead** was found in the whole basin. This pollution can be seen particularly at the entrance and in the rest of the system.

For the Copper

In 2005, the concentrations of **Copper** (table 8 and figure 4) are ratter constant in the whole basin except in the former part of the basin where the concentrations are much more significant.

In 2006, the concentration of **Copper** is shown relatively constant in the part rehabilitated. However, the intensification of the pollution is particularly visible in the former part of the basin.

In 2007, the concentrations of **Copper** are remarkably obvious in the former part of the basin and also at the entrance of the latter. But the concentration in the rest of the system is relatively constant.

Table 7. Average concentration, standard deviation and Cv for the three campaigns in two parts of the basin (Pb)

	Pb	Apr.-05	Feb.-06	Jul.-07
Part of the former system:	Average (mg/kg)	138	145	183
	Median(mg/kg)	148	152	170
	Standard deviation (mg/kg)	44	42	46
	Cv (%)	32	29	25
Rest of system :	Average (mg/kg)	53	195	241
	Median(mg/kg)	44	122	226
	Standard deviation (mg/kg)	30	209	89
	Cv (%)	58	107	37

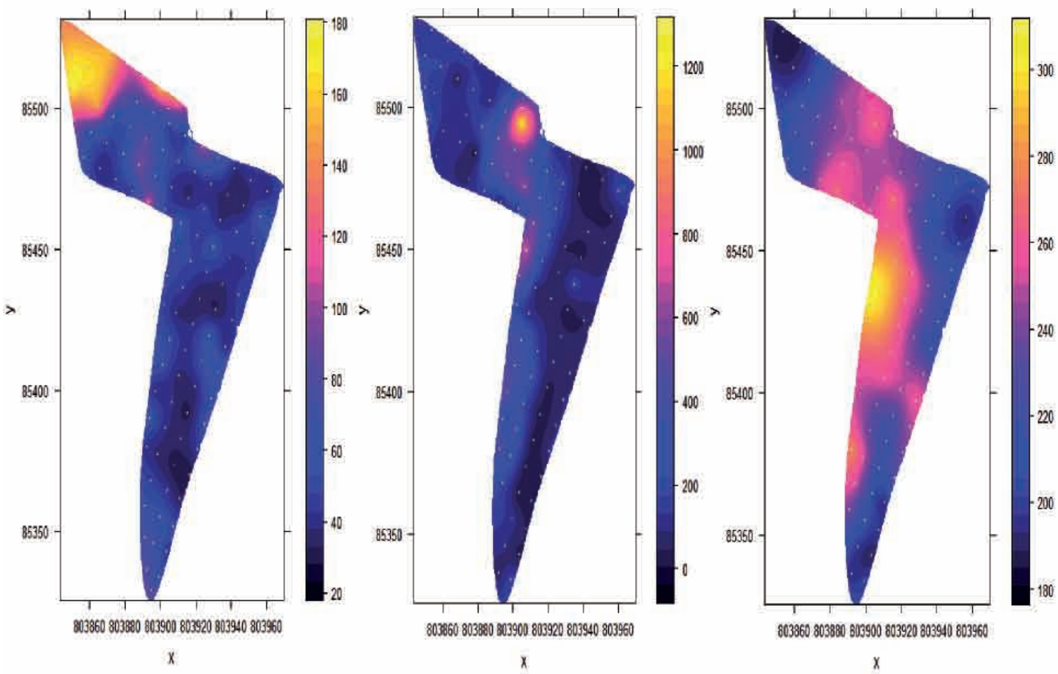

Figure 3. Contents in Pb: (April, 2005), (February, 2006) and (July, 2007)

Table 8. Average concentration, standard deviation and Cv for the three campaigns in two parts of the basin (Cu)

	Cu	**Apr.-05**	**Feb.-06**	**Jul.-07**
Part of the former system :	Average (mg/kg)	261	238	239
	Median(mg/kg)	281	266	253
	Standard deviation (mg/kg)	102	100	94
	Cv (%)	39	42	39
Rest of system :	Average (mg/kg)	88	167	209
	Median(mg/kg)	66	178	219
	Standard deviation (mg/kg)	73	105	68
	Cv (%)	83	63	33

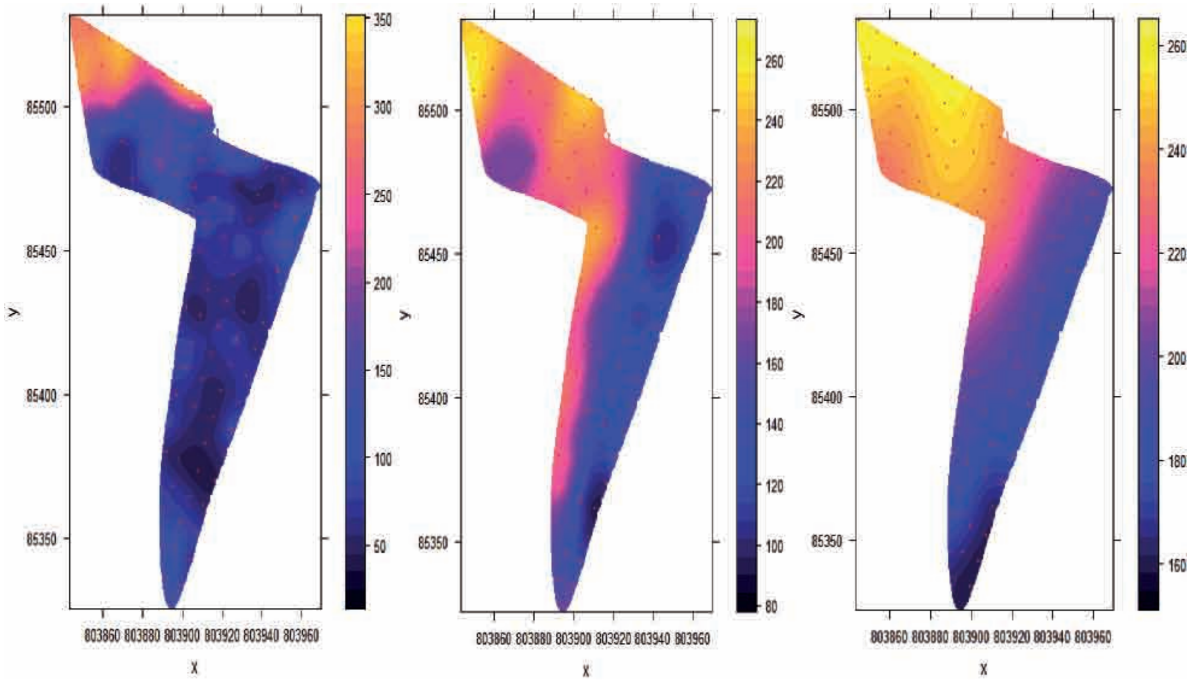

Figure 4. Contents in Cu: (April, 2005), (February, 2006) and (July, 2007)

For the Zinc

In 2005, the largest concentrations of **Zinc** (Table 9 and figure 5) are found in the former part of the basin, and in the rest of the basin the concentrations are constant.

In 2006, the concentrations are larger in the former part of the basin and relatively constant in the rest of the basin. The pollutants which are developing in it are shown clearly as well, but the pollutants distribution with the surface is not as obvious as it is for the other pollutants. So the **Zinc** seems to be the most mobile metal of the space.

For the **Zinc in 2007**, the concentrations remain constant is the whole basin; but the largest concentration is shown in the former part of the system.

Table 9. Average concentration, standard deviation and Cv for the three campaigns in two parts of the basin (Zn)

	Zn	Apr.-05	Feb.-06	Jul.-07
Part of the former system:	Average (mg/kg)	2275	2143	1920
	Median (mg/kg)	2303	2082	1741
	Standard deviation (mg/kg)	1033	939	675
	Cv (%)	45	44	35
Rest of system :	Average (mg/kg)	624	969	1206
	Median (mg/kg)	486	1052	1241
	Standard deviation (mg/kg)	408	544	356
	Cv (%)	65	56	30

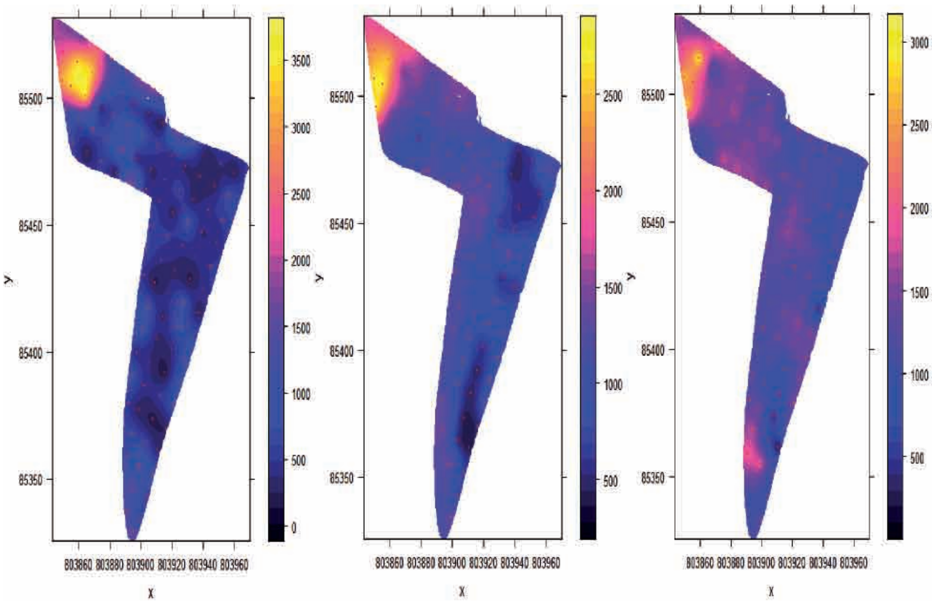

Figure 5. Contents in Zinc: (April, 2005), (February, 2006) and (July, 2007)

Mass of Pollutants trapped in the first five centimeters

The total mass of pollutants trapped by the soil in the 5 cm is calculated by the equation 1 for each pollutants considered.

The uncertainty of the mass assessment concerns the pollution of the local variability, the uncertainty in the soil density, in the percentage of the thin fraction of the soil and in depths. The mass assessment and them uncertainty are shown in the table 10.

The masses of Lead are increased in the Django Reinhardt basin of 46 kg, of 30 kg for the copper and of 134 kg for the Zinc.

The evolution of concentration masses of Lead, Copper and Zinc according to the years in question are shown in the graph below (Figure 6).

Table 10. Masses of pollutants trapped in 5 cm

	Pb (Kg)	Cu (Kg)	Zn (Kg)
April 2005	15 ± 6	26 ± 11	199 ± 86
February 2006	48 ± 21	45 ± 19	282 ± 122
July 2007	61 ± 27	56 ± 24	333 ± 145
Total masses trapped	46 ± 21	30 ± 13	134 ± 59

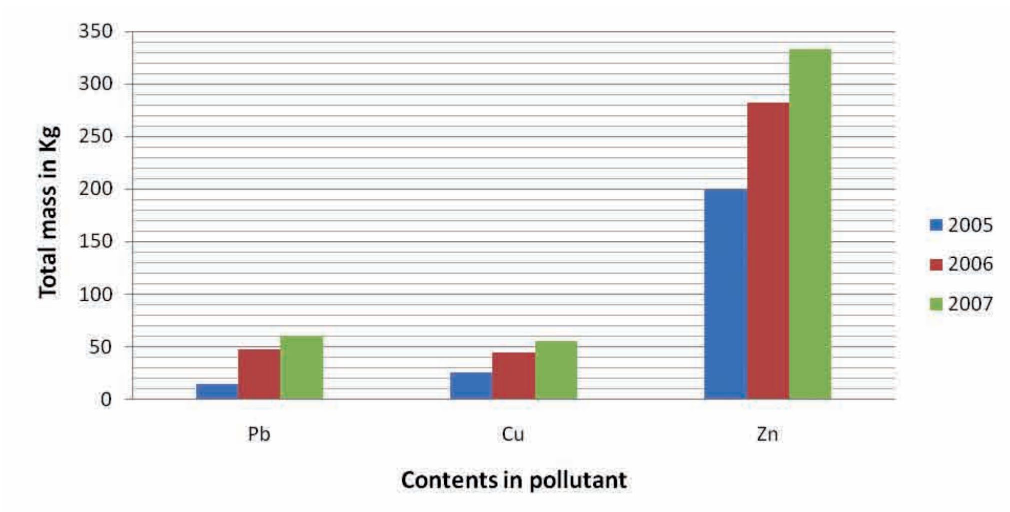

Figure 6. Concentrations masses of evolution in Pb, Cu and Zn

CONCLUSION

In this study, we suggested the use of the ordinary Krigeage method for the characterization of the spatial heterogeneity of trapped pollutants in a way to evaluate correctly the masses retained by the soil and the evolution pollutants charges.

The interpretation of the results obtained allowed noticing that:

The correlation between the heavy metals of the first campaign is much larger than those of the second and third campaign.

For the three sampling campaigns undertaken, the pollution is felt very large in the upper level of the system that is in the first 5 cm of the studied soil.

The concentration in heavy metal is often higher in the most former part of the basin than in the rest of the system. This concentration seems to be relatively constant.

The attracted zones, in terms of hydraulic and at the entrance of the basin have higher concentration of heavy metals (Lead, Zinc and Copper).

The spatial heterogeneity is important, but unfortunately all the pollutants do not have the same reaction. The Zinc seems to be the most mobile metal of the system.

The mass assessment has been built up again in the basin for the different metal studied. It's obvious that the total mass of pollutants built up again in the first 5 centimeters of the studied soil is getting increased from one year to another.

In order to continue with the research works presented in this dissertation, other method of Krigeage should be considered or studied, such as, Universal Krigeage and other types of spatial interpolation methods, as well as the different spatio-temporal interpolation method. All these methods should be particularly interesting to use as solution to the interpolation problematic of data.

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REFERENCES

Bachoc A., Chebbo G. et Mouchel J.M. 1992. La pollution des rejets pluviaux urbains : son importance, ses caractéristiques, quelques éléments sur ses origines et son interception. Rejets urbains par temps de pluie : pollution et nuisances. Actes des 3èmes journées du DEA Sciences et Techniques de l'Environnement, organisées les 14 et 15 mai 1992 à Paris, pp. 9-21.

Bardin J.P, Gautier A., Barraud S. et Chocat B. 2001. The purification performance of infiltration basins fitted with pre-treatment facilities: A case study. Water Science and Technology, vol. 43, n° 5, pp. 119-128.

Bardin J.-P., Barraud S. 2004. Aide au diagnostic et à la restructuration du bassin de rétention de Chassieu. INSA de Lyon - URGC Hydrologie Urbaine. Villeurbanne France : Rapport pour le compte de La Direction de l'Eau du Grand Lyon, juin 2004, 62 p.

Boller M. 2004. Towards sustainable urban stormwater management. Water Science and Technology : Water Supply, vol. 4, n° 1, pp. 55-65.

Brelot E. 1994. Eléments pour la prise en compte de l'impact des rejets urbains sur les milieux naturels dans la gestion des systèmes d'assainissement. Doctorat: INSA Lyon France, 352 p.

BRGM 2000. Gestion des sites potentiellement pollués. Evaluation simplifiée des risques et classification des sites. Version 2. Editions BRGM.

Chocat B. 1997. Encyclopédie de l'hydrologie urbaine et de l'assainissement. Edition Tec & Doc, Lavoisier, Paris, 1136 p.

Chocat B., Desbordes M. et Brelot M. 2004. NOVATECH : Synthèse de trois années de progrès scientifiques et techniques dans la gestion urbaine des eaux pluviales, Lyon France, 11 p.

Dechesne M. 2002. Connaissance et modélisation du fonctionnement des bassins d'infiltration d'eaux de ruissellement urbain pour l'évaluation des performances techniques et environnementales sur le long-terme. Doctorat : INSA Lyon France, 275 p.

Dechesne M., Barraud S., Bardin J.P. 2004. Indicators for hydraulic and pollution retention assessment of stormwater infiltration basins. Journal of Environmental Management. 714.

Fischer D., Charles E. G. et Baehr A. L. 2003. Effects of stormwater infiltration on quality of groundwater beneath retention and detention basins. Journal of environmental engineering, vol. 129, no5, pp. 464-471.

Forster J. 1990. Roof runoff: a source of pollutants in urban storm drainage systems? In 5th International Conference on Urban Storm Drainage, Osaka, Japan, pp.468-474.

Forster J. 1996. Patterns of roof runoff contamination and their potential implications on practice and regulation of treatment and local infiltration. Water Science and Technology, vol. 33, n° 6, pp. 39-48.

Forster J. 1999. Variability of roof runoff quality. Water Science and Technology, vol. 39, n° 5, p. 137-144.

Lind B. et Karro E. 1995. Stormwater infiltration and accumulation of heavy metals in roadside green areas in Göteborg, Sweden. Ecological Engineering, vol. 5, pp. 533-539.

Makepeace D.K., Smith D.W. et Stanley S.J. 1995. Urban stormwater quality: summary of contaminant data. Critical Reviews in Environ. Sc. Technol. 252: 93-139

Nightingale H. 1987. Accumulation of As, Ni, Cu, and Pb in retention and recharge basins soils from urban runoff. Water Resource Bulletin, vol. 23, pp. 663-672.

Person A., Petit-Coviaux F., Le Moullec Y. et Festy B. 1993. Contribution des principales sources en métaux et métalloïdes à la pollution particulaire dans l'agglomération parisienne. Pollution Atmosphérique, pp. 75-88.

R Development Core Team 2006. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Thevenot D. 1992. Pollution des eaux pluviales urbaines : origine, niveaux et mobilité des polluants. Dans Rejets urbains par temps de pluie : pollutions et nuisances. Presses de l'Ecole nationale des ponts et chaussées, pp. 81-93.

Winiarski T., Delolme C., Bedell J.-P., Ghidini M., Crosnier J., et Bobillon G. 2001. Profils chimique, biologique et perméabilité du bassin Django Reinhardt. Rapport final. Ecole Nationale des Travaux Publics de l'Etat, Lyon.

Yousef Y.A., Hvitved-Jacobsen T., Sloat J. et Lindeman W. 1994. Sediment accumulation in detention or retention ponds. The Science of the Total Environment, vol. 146-147, pp. 451-456.