Comparison between different approaches for the definition of soil contamination indicators of stormwater infiltration systems

Comparaison de différentes approches pour la définition d'indicateurs de contamination des sols des systèmes d'infiltration des eaux pluviales

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RESUME

L'usage des systèmes d'infiltration dans la gestion des eaux pluviales est de plus en plus courant dans les zones urbaines françaises. Les bassins d'infiltration secs sont les plus utilisés. En dépit des avantages qu'ils présentent, de nombreux questionnements subsistent quant à leur évolution sur le long terme. En effet, leur vieillissement pose deux problèmes majeurs : le colmatage et la contamination éventuelle du sol et des nappes. Pour évaluer cette contamination, des indicateurs de pollution des sols se sont révélés des outils intéressants. L'objet de cet article est de présenter deux approches ayant été testées pour la construction d'indicateurs de contamination des sols. La première est basée classiquement sur des caractéristiques physicochimiques des sols, la deuxième sur leur potentielle écotoxicité.

ABSTRACT

The use of infiltration systems to manage stormwater is becoming widespread in French urban areas. Dry infiltration basins are the most popular form. Despite their advantages, their long-term sustainability is often questioned. Over time, two major problems are encountered: clogging and potential contamination of the soil and groundwater systems. To evaluate soil contamination and the groundwater contamination, indicators turned out to be interesting tools. To define such indicators two approaches were proposed: one is based on conventional pollution physicochemical characteristics, and the other on ecotoxicological tests.

KEYWORDS

Bioassays; Ecotoxicological tests; Stormwater infiltration systems; Urban drainage.

1 INTRODUCTION

The use of infiltration systems to manage stormwater is becoming widespread in French urban areas. The dry infiltration basins, often coupled with retention compartments, are the most popular form. Different factors explain this preference for infiltration basins. The use of infiltration basins reduces water volumes in downstream networks and limits pollution discharges to surface waters. They also promote urban development in areas distant from existing networks or natural outlets and enhance urban sites where basins are designed as parks or playgrounds for example. Lower costs and groundwater recharge are other attractive aspects of these techniques.

Despite these advantages their long-term sustainability is often questioned. Over time, two major problems are encountered: clogging and potential contamination of the soil and groundwater systems (Pitt et al., 1999). Different studies have brought forward the role of the topsoil layer which seems to be a very effective trap so that the groundwater quality does not seem to be affected by stormwater infiltration (e.g. Mikkelsen et al., 1994).

Even if the soil can be considered as an efficient pollution barrier especially for heavy metals and hydrocarbons including PAHs (Polycyclic Aromatic Hydrocarbons), the soil pollution has to be controlled and studied in order to qualify its toxicity, its evolution and the possible contamination of deeper layers. For that purpose, contamination indicators turned out to be interesting tools.

2 SOIL CONTAMINATION INDICATORS

For that purpose, two main approaches has been tested for the proposition of soil contamination indicators: one is based on conventional physicochemical characteristics, and the other on ecotoxicological tests.

Contamination indicators, founded on the first approach, can be defined according to pollutant concentrations measured in a basin soil compared to reference values (i.e. from reference soil samples, from national or regional standards …).

This approach comes up against several drawbacks. It requires to define an *a priori* list of pollutants; reference thresholds have to be defined and there is no consideration for the interaction between pollutants. At the present, the pollutants are chosen according to the current knowledge, basically heavy metals, hydrocarbons, nutrients, VOCs,… but who knows if other substances are not as important although not taken into account. The definition of thresholds is often discussed and is a still controversial topic. Nevertheless chemical analysis can not express the multiple interactions between pollutants and do not take into account the bioavailability of the chemicals. The increasing awareness of the limitation of the chemical approach has led to a biological approach. That is the reason why a second approach based on ecotoxicological tests has been proposed.

The ecotoxicological approach is founded on the overall answer of a tested biota to the simultaneous exposure to all chemicals present in a polluted environmental compartment, their respective concentrations, bioavailabilities and interactions (Persoone et al., 1993). Ecotoxicology integrates ecology and toxicology and aims to understand and predict effects of chemicals on natural communities under realistic exposure conditions (Chapman, 2002). According to the definition, the impact includes immediate or delayed adverse effects on biotic systems; the toxicity to the individual organisms is used as an indicator of toxic impact on these systems. In ecotoxicology the toxicological properties of the substances and their exposure-related properties are considered, the toxic impact on biotic systems of substances or mixtures of substances is assessed by means of tests, in which organisms are exposed under controlled conditions. An ecotoxicological assessment should also address acute effects (e.g. acute lethality of organisms) as well as chronic effects (e.g. reduced growth or failure of reproduction) as endpoints.

3 RESULTS AND DISCUSSION

3.1 The physicochemical approach

This physicochemical approach has led to define indicators whose definition has changed over the time.

The first set of indicators was proposed by Barraud et al. (2001). One was defined as the depth where pollutant concentrations reach an acceptable value (reference concentration) (Equation 1) and the other as the mean ratio of pollutant concentrations of the topsoil to a reference concentration (Equation 2).

$$IP_{6\text{-}1} = z_{lim} \ / \ \forall \ z > z_{lim} \ \Rightarrow \ T_{soil}(z) < T_{ref} \ \text{and} \ IP6-2 = \overline{\left[\frac{T_{soil}}{T_{ref}}\right]} \qquad (1, 2)$$

T_{soil} (z): mean pollutant concentration in the soil at the depth z under the infiltration system, T_{ref}: reference concentration, Tsoil: mean pollutant concentration of the topsoil.

These definitions were applied to four infiltration basins (Cf. Table 1). To evaluate this set of indicators, soil samples were taken at different depths and different points taken all over the basin bed.

The indicators were calculated using the concentrations of metals (Cd, Cr, Cu, Ni, Pb, Zn and Hg) and those of a reference soil sampled next to one of the basins.

The results show a low sensitivity of IP6-1, it wasn't able to differentiate situations that were known dissimilar. For example the pollution in the basin ZAC du Chêne is spread all over the basin whereas the pollution in ZAC de Pivolles is much deeper but only located near the basin inlet.

	Droits de l'Homme	Centre Routier	ZAC du Chêne	ZAC de Pivolles
IP6-1	> 90 cm	> 90 cm	> 90 cm	> 90 cm
IP6-2	5.91	4.33	6.31	7.41

Table 1 – Indicators IP6-1 and IP6-2 calculated by the equations 1 and 2

The second set of indicators, was proposed by Dechesne et al. (2004). The contamination indicators considered two aspects: the depth where the pollution becomes low and the spatial pollution extent. For both aspects and for different pollutant, the contamination indicators were defined according to two types of thresholds (Dutch standards, NMHSPE, 2000): one related to target values characterizing a "natural" soil quality and one related to intervention values quantifying a limit over which functional properties for human, plant and animal life are threatened. The soil contamination is considered as insignificant for a given layer if there is a very high percentage of pollutants where concentrations are lower than target values and none are higher than the intervention limit. Then a second indicator evaluates the percentage of highly polluted samples. A sample is supposed to be polluted as soon as a pollutant presents a concentration higher than the intervention value.

Therefore, this performance was based on two components K_1 and K_2 (Dechesne et al, 2004).

$$K_1 = \frac{\sum_{C_i < C_{DSt}} w_i}{\sum w_i} \ \text{and} \ K_2 = \frac{\sum_{C_i > C_{DSi}} w_i}{\sum w_i} \qquad (3, 4)$$

w_i : toxic weight of pollutant i, C_i : pollutant i concentration in the basin soil, C_{DSt} : pollutant i target value given by Dutch Standards (NMHSPE, 2000), C_{DSi} : pollutant i intervention value given by Dutch Standards (NMHSPE, 2000).

This definition implied that if a single pollutant exceeds Dutch Standards intervention values, the entire soil layer was considered polluted.

The two contamination indicators are:

IP6-1: depth where pollution becomes low or nil. A low pollution is characterized by a high K_1 ($K_1 \in [1-x, 1]$, where x is an exigency threshold);

IP6-2: percentage of highly polluted soil samples. A sample is highly polluted when $K_2 \neq 0$.

The toxicity weights are defined for each pollutant according to French Standards on drinking water (Decree 89-3, 1989) with weights ranging from 1 to 3, 3 being the most toxic.

The results given by the indicators IP6-1 and IP6-2 for the four infiltration basins are presented in the Table 2. It can be observed that the indicators make the difference between the basins, which were known dissimilar.

	Droits de l'Homme	Centre Routier	ZAC du Chêne	ZAC de Pivolles
IP6-1	40-45 cm	30-40 cm	30-35 cm	> 90 cm
IP6-2	33%	30%	44%	22%

Table 2 – Indicators IP6-1 and IP6-2 calculated by the equations 3 and 4

Even presenting robust results this proposition was controversial. It was mainly due to the application of Dutch Standards to evaluate French soils; and the use of toxicity weights. In effect, the notion of target seemed sufficient to indicate the importance of the toxicity, the weights were then considered to be redundant.

Consequently another definition of the indicators was proposed, based on the same basis than the previous one. It uses French Standards thresholds and a reference soil concentration to calculate K_1 and K_2 and no toxic weights were taken into account.

$$K_1 = \frac{\#\text{cas}[C_{mesi} \leq NH_{Ci}]}{\#_{totpol}} \text{ and } K2 = \frac{\#\text{cas}[C_{mesi} \geq NH_{Ii}]}{\#_{totpol}} \qquad (5, 6)$$

#cas : number of pollutants for which the case between [ ] is true, $\#_{totpol}$: total number of pollutants, C_{mesi} : measured concentration of the pollutant i, NHCi : pollutant concentrations in the reference soil, NHIi : pollutant concentration for which the soil is considered as a source of pollution (BRGM, 2000).

The results of the indicators calculated for the same four basins are presented in Table 3.

	Droits de l'Homme	Centre Routier	ZAC du Chêne	ZAC de Pivolles
IP6-1	> 90 cm	> 90 cm	> 90 cm	> 90 cm
IP6-2	22%	33%	33%	22%

Table 3 – Indicators IP6-1 and IP6-2 calculated with equations 5 and 6

Unfortunately, the IP6-1 was not sensitive enough, once again.

A last definition for the indicator was proposed. It uses only one threshold, but taking into account the uncertainties. It is based on Equation 7.

$$K_1 = \frac{\#\text{cas}[C_{mesi} \leq VDSS_i]}{\#_{totpol}} \qquad (7)$$

#cas : number of pollutants for which the case between [ ] is true, $\#_{totpol}$: total number of pollutants, C_{mesi} : measured concentration of the pollutant I, VDSS : pollutant concentration for which the soil is considered as a source of pollution (BRGM, 2000).

For the definition of the pollution degree of the infiltration system two indicators were defined: IP6-1 the depth where pollution becomes low or nil, characterised by $K_1 \in [1-x, 1]$ and IP6-2 the percentage of highly polluted soil points. A point is highly polluted when $K_1 > 0$.

Table 4 presents the results of the calculation of the indicators. The results obtained are coincident with the situation observed in the basins, indicating a quality proposition.

	Droits de l'Homme	Centre Routier	ZAC du Chêne	ZAC de Pivolles
IP6-1	35-40 cm	30-40 cm	30-35 cm	>90 cm
IP6-2	70%	100%	66%	33%

Table 4 – Indicators IP6-1 and IP6-2 calculated with equation 7

3.2 Ecotoxicological approach

This approach was used in two ways. The first one was applied in order to verify whether current soil of infiltration systems have a significant ecotoxical impact. The second way was to use these tests to help in the re-definition of contamination indicators.

For those two purposes, ecotoxicological tests were carried out on the soil of an urban stormwater infiltration basin located in the eastern part of Lyon – France. Its ecotoxicity were compared to an urban ordinary top soil sampled near the studied basin (called reference soil or tested substrate).

The physicochemical characteristics of the soil are given in Table 5.

Substance	Test subs.	Basin	Substance	Test subs.	Basin
Al	12000	7600	Carbonic fraction C10-C12	<10	<10
As	15	5,6	Carbonic fraction C12-C14	<10	<10
Cd	0,32	0,67	Carbonic fraction C14-C16	<10	<10
Cr	21	31	Carbonic fraction C16-C21	<10	110
Cu	41	100	Carbonic fraction C21-C35	<10	1200
Mn	490	270	Carbonic fraction C35-C40	<10	190
Hg	0,22	0,17	Naphtalene	<0,01	<0,05
Pb	59	81	Acénaphthylene	<0,01	<0,05
Si	130	72	Acénaphthene	<0,01	<0,05
Zn	77	1300	Fluorene	<0,01	<0,05
P	520	1100	Phénanthrène	<0,01	0,08
Mg	1500	2200	Anthracene	<0,01	<0,05
K	1200	1100	Fluoranthene	0,02	0,2
Na	62	140	Pyrene	0,02	0,19
Ca	2300	16000	Benzo(a)anthracene	0,01	0,1
N total	1440	8300	Chrysene	0,01	0,13
TOC	1,3	9,7	Benzo(b)fluoranthene	0,02	0,18
TC	2,8	13	Benzo(k)fluoranthene	<0,01	0,06
TIC	1,5	3,3	Benzo(a)pyrene	0,01	0,11
Dry Matter	92,5	61,1	Dibenzo(ah)anthracene	<0,01	<0,05
CEC*	116	245	Ideno(1,2,3-cd)pyrene	<0,01	<0,07
TH[1]	<10	680	Benzo(ghi)perylene	0,01	0,12
TH[1] (GC-FID)	<10	1500			

([1]Total Hydrocarbon)

Table 5 - Concentration of different substances in the test substrate and in the basin soil - Concentrations in mg/kg of dry matter (except CEC * in Meq/kg)

To evaluate the ecotoxicity of the basin soil, three ecotoxicological tests have been made in the soil matrices. The first one concerns the germination inhibition of the ray grass, in order to verify its emergence and growth (NF X31-201). The two others are applied to earthworms submitted to mortality (ISO 11268-1) and avoidance tests (ISO/CD 17512). All the tests were realised in triplicates.

The test to measure the seeds germination inhibition consists in planting 20 seeds of ray grass (*Lolium perenne*) in the non polluted soil and in the polluted soil at different concentrations (i.e. 100%, 50%, 10% and 1%). The reference soil was used to dilute the basin soil.

After some weeks the number of seeds that germinate are counted and a comparison is made with the number of germinated seeds in the non polluted soil. The difference allows evaluating the toxicity of the contaminated soil. The results are presented in Figure 1. For all the tests, the number of germinated seeds is very close to the 20 seeds planted.

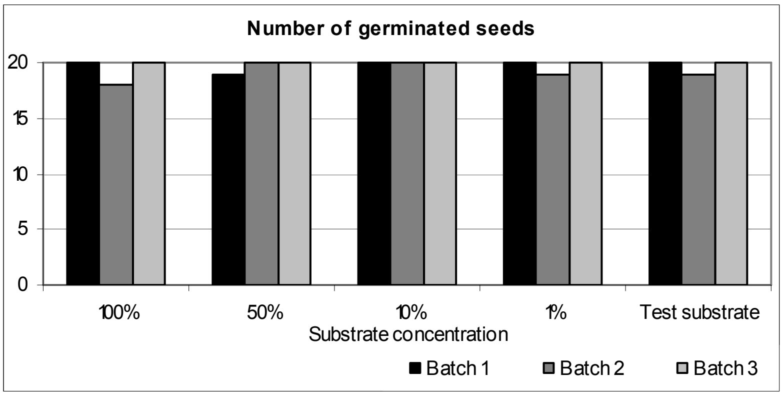

Figure 1 – Results of the test of inhibition of seeds germination -
Number of seeds germinated after 4 weeks

To test the capacity of the seeds to germinate, the developed plants were weighted and their mass compared to the mass of the plants developed in the reference soil. The average weights of the plants are shown in Table 6 according to each substrate concentration. No significant variability between the mass of the germinated plants in the test substrate and in the basin soil was observed.

For the inhibition of ray grass seed germination, the observed experimental conditions in the basin soil don't induce any inhibition of the growth of the tested seeds.

Concentration	Dry mass after the end of the assay (in 10 plants)
100%	1.931 g
50%	1.949 g
10%	1.943 g
0%	1.932 g

Table 6 – Results of the test of inhibition of seeds germination – mass after 4 weeks exposition

The effects of the pollutants on earthworms (*Eisenia fetida*) was then tested in order to determinate the acute toxicity of soil.

For that purpose, ten adult earthworms were placed in a defined substrate at different concentrations allowing the determination of the mortality after 14 days. This test was carried out with three different basin soil concentrations: 100%, 50% and 1%, and the results were compared to those obtained with the test substrate. The dilution soil was the test substrate like in the ray grass test. The results are shown in Figure 2.

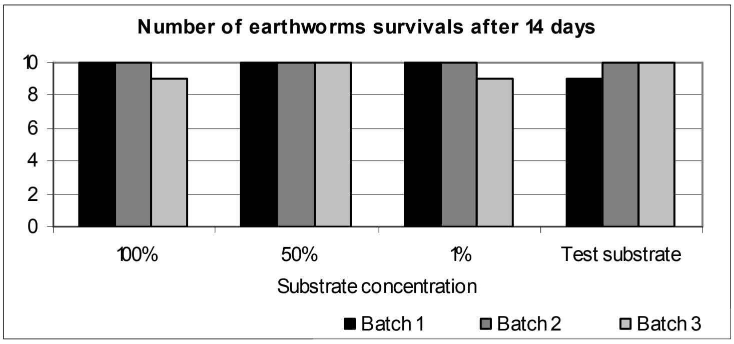

Figure 2 – Number of earthworms survivals after 14 days

The results of earthworm mortality do not demonstrate a significant difference between the test substrate and the basin soil. Low mortality was observed in this test. In the observed experimental conditions, the basin soil doesn't induce earthworm mortality.

An avoidance test was then performed with earthworms. The avoidance tests were established in cylindrical plexiglass vessels. Each of these vessels was divided into two equal sections. One-half of the vessel received control soil (test substrate) and the other half contaminated soil (basin soil). Ten earthworms were placed in the separating slit between the sections. After the test period, the numbers of earthworms in both sections were counted. The avoidance test was carried out with three different soil concentrations: 100%, 50% and 10% and the dilution soil was the reference soil.

The results can be observed in Figure 3, after 24 hours of exposition. In average earthworms were equally divided between the two substrates, demonstrating no avoidance to a particular substrate, in the observed experimental conditions.

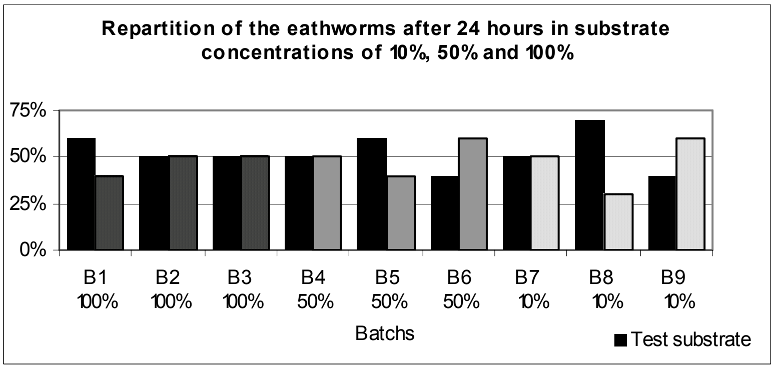

Figure 3 – Results of the avoidance test - Repartition of the earthworms after 24 hours exposition

According to these results, the basin soil is not toxic for the organisms tested and in the conditions where the tests were executed.

About the ecotoxicological approach, no conclusive result was obtained for the proposition of a soil contamination indicator.

4 CONCLUSIONS

Two approaches have been tested for the proposition of soil contamination indicators: one based on physicochemical characteristics and another based on ecotoxicological tests. For the first approach, different propositions were presented and a final definition given. However, the method requires to define an *a priori* list of pollutants, no interaction between pollution is considered and one never knows if other substances has not a major but ignored effect.

The ecotoxicological approach was envisaged as an interesting alternative to define basin pollution indicator. However the ecotoxicological tests carried out presented no exploitable results for that purpose because of its lack of sensitivity. However, it gives interesting information. An infiltration basin soil does not seem to be toxic for the organisms tested and in the conditions where the tests were done.

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