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Spatial variability of sediment ecotoxicity in a large storm water detention basin

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Abstract Detention basins are valuable facilities for urban storm water management, from both the standpoint of flood control and the trapping of pollutants. Studies performed on storm water have shown that suspended solids often constitute the main vector of pollutants (heavy metals, polycyclic aromatic hydrocarbon (PAH), etc.). In order to characterise the ecotoxicity of urban sediments from storm water detention basins, the sediments accumulated over a 6-year period were sampled at five different points through the surface of a large detention basin localised in the east of Lyon, France. A specific ecotoxicological test battery was implemented on the solid phase (raw sediment) and the liquid phase (interstitial water of sediments). The results of the study validated the method formulated for the ecotoxicological characterization of urban sediments. They show that the ecotoxicological effect of the sediments over the basin is heterogeneous and greater in areas often flooded. They also show the relationship between, on one hand, the physical and chemical characteristics of the sediments and, on the other hand, their ecotoxicity. Lastly, they contribute to a better understanding of the dynamics of the pollution close to the bottom of detention basins, which can be useful for improving their design. The results of this research raise particularly the issue of using oil separators on the surface of detention basins.

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Introduction

Rapid urbanization in many countries raises challenges for conventional drainage systems. Increasing volumes of storm water and peak flows due to urbanization can lead to more frequent urban floods (Ellis and Hvitved-Jacobsen 1996; Marsalek 1998). Moreover, the suspended particles carried in urban storm water have been recognized as one of the major sources of pollution for natural receiving water (Chebbo et al. 2003; Rossi et al. 2004; Scholes et al. 2008; Zgheib et al. 2012). Therefore, it is particularly important to adopt appropriate infrastructural designs and operating strategies in storm water management practice. Detention basins are among the most common measures aimed at reducing the impacts of urbanization on receiving waters and ensure the treatment of suspension particles by settling (Schueler et al. 1992; Marsalek and Chocat 2002; Wong 2006; Rivard et al. 2005). The potential hydrological advantages of detention basins include ensuring flow regulation to minimize storm water outflow for flood prevention and for environmental purposes and treating suspended particles.

A detention-settling basin is essentially an artificial shallow pond that is typically constructed on sites by simple excavation. Detention basins are designed to retain a volume of water to improve the treatment of suspension particles by settling. However, over time, the pollutant detention capacity decreases, and water quality can deteriorate due to the accumulation of sediments (MOEE 1994; Marsalek et al. 1997). Therefore, these structures require maintenance and specific sustainable management. Consequently, it is necessary to consider the following: (1) the main zones in which sediments are deposited most frequently to improve sustainable management and (2) different potential uses for these sediments (e.g. filling material in urban environments, use in the formulation of new products, etc.). However, each use requires prior characterization of their ecotoxicity, in order to verify that they are not dangerous for human or environmental health.

To achieve this, chemical analysis is an essential but insufficient tool. Indeed, it is now accepted that total chemical content does not systematically permit assessing toxicity to living organisms. It is also acknowledged that combined actions linked to the presence of mixtures of pollutants (e.g. synergetic and/or antagonistic effects) cannot be predicted on the basis of a list of these pollutants (even if detailed). Thus, bioassays (or ecotoxicity tests) can contribute towards solving these problems (Perrodin et al. 2010) and represent a powerful tool for the management of urban detention basins and the protection of aquatic ecosystems (Marsalek et al. 1999).

The Django Reinhardt detention-settling basin in Chassieu (east Lyon) was monitored in the framework of the CABRRES's project. This basin is connected to an infiltration basin. The main purposes of this project can be listed as follows: (1) to develop a hydrodynamic model to predict the contamination areas in the detention basin, taking into account the dispersion of particulate contaminants (the particulate phase being the major vector of chemical and microbiological contaminants), considering shearing and turbulent kinetic energy, and (2) to characterize the microbiological, physico-chemical and ecotoxicological properties of the deposits. An initial field campaign was carried out in the framework of this project in May 2012, including very detailed bio-physicochemical characterization of accumulated sediments from storm water detention basin.

The objectives in this paper include the following: (1) identifying the pertinence of ecotoxicological tests in the liquid and/or solid phase and (2) analysing the toxicity of sediments linked to their physical characteristics (e.g. size distribution) and the relationship with spatial settling.

The ecotoxicity of urban sediments has been studied by implementing a battery of ecotoxicological tests formulated on the basis of the results obtained from first works performed on storm water (Moura et al. 2007; Angerville et al. 2013; Becouze-Lareure et al. 2012). The use of a battery of toxicity tests is necessary because of varying sensitivity of these tests to various stressors. The battery selected was studied for sediments from several detention basins, and the results suggested that tests on the solid phase highlight the ecotoxicological effects of urban sediments (Gonzalez-Merchan et al. 2013).

In this paper, we describe the analysis of the ecotoxicological effect of urban accumulated sediments taken from five different points located on the surface of a large detention basin. The results of this study will be used to improve the monitoring of urban sediments in storm water detention basins and contribute to the sustainable management of these systems.

Description of sites

The detention and infiltration basin analysed in this study is located at Chassieu, in the eastern suburbs of Lyon, France (www.othu.org). It has an urban and industrial drainage watershed of 185 ha, with rather flat topography (mean slope 0.4 %) and an imperviousness coefficient of about 75 %.

Storm water flows are successively discharged into the detention/retention basin whose area and volume are about 1 ha and 32,000 m^3, respectively. The system then channels the water into an infiltration basin. Similar systems for the detention and treatment of urban storm water are found in most major cities in Europe, Canada and USA. The major weakness of such systems is that sediments are resuspended during a rainfall event, with the possibility that volatile, toxic or infectious substances are remobilized, representing a major risk for local residents and the natural environment (i.e. soil and/or water). Figure 1 shows the configuration of the Django Reinhardt detention–infiltration basin. The basin sides are composed of natural soil slopes covered with a tightly stretched plastic film. The basin has been functioning for more than 30 years and was rehabilitated in 2002. All the sediments were removed in 2006.

The storm water flow rate and quality at this site are monitored continuously with a time step of 2 min, e.g. turbidity, which is often used to estimate the TSS and COD of the discharge (Bertrand-Krajewski 2004). Climatic factors (air, water temperature, solar energy and rainfall) are also monitored. Intermittently, the detention basin receives dry weather effluents from industrial cooling processes that are supposed to be clean.

More details on the site and the monitoring system can be found in Barraud et al. (2002) and Bertrand-Krajewski et al. (2008).

Experimental methods

Sampling

A field campaign was performed in May 2012. The physical, chemical and ecotoxicological parameters were measured on the sample sediments corresponding to five representative points located on the bottom of the detention basin. These points were chosen according to recirculation zones, flow velocities and sediment accumulation observed in the system. The positions of the points are shown in Fig. 2. Point P12Bis corresponds to a rough oil separator (in fact, a small settling tank) which traps hydrocarbons and waste from dry weather flows by gravity.

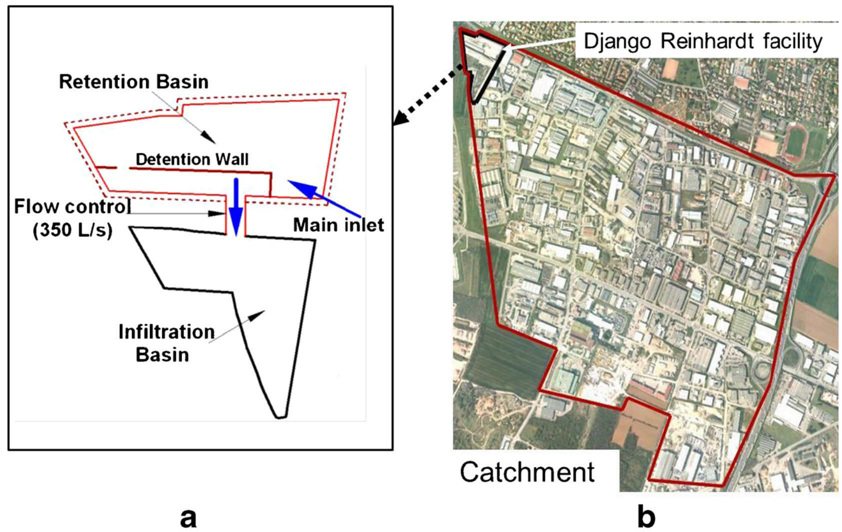


Fig. 1 **a** Configuration of the whole experimental Django Reinhardt site. **b** Aerial view of the Chassieu catchment and of the Django Reinhardt facility at the north-west corner

Sediments from sampling sites P01, P02, P04 and P07 had moisture contents ranging from 10 to 60 % during dry episodes. In order to obtain representative samples, the total thickness of stored sediments at each zone was homogenised by careful mixing and quartering 1 m×1 m on the surface. Point P02 corresponds to a particular point for which three layers of sediment were sampled: surface (P02-S), middle (P02-I) and bottom (P02-B). All the sediments assessed exhibited a peaty visual aspect with a low dry bulk density ranging from 600 to 700 kg/m^3 (Sebastián et al. 2013).

The ecotoxicological tests were carried out for the solid and aqueous phases. The solid phase corresponded to the “raw” sediment sampled after homogenisation; the aqueous phase was extracted from the raw sediment after centrifugation for 40 min at 9,000 rpm.

This protocol was set up in order to highlight (1) the potential ecotoxic effects of the sediments and (2) the toxic effects of the interstitial water of the sediments containing pollutants that can be easily mobilised on site by the action of storm water and thus reach different compartments of the natural environment (i.e. soil and groundwater).

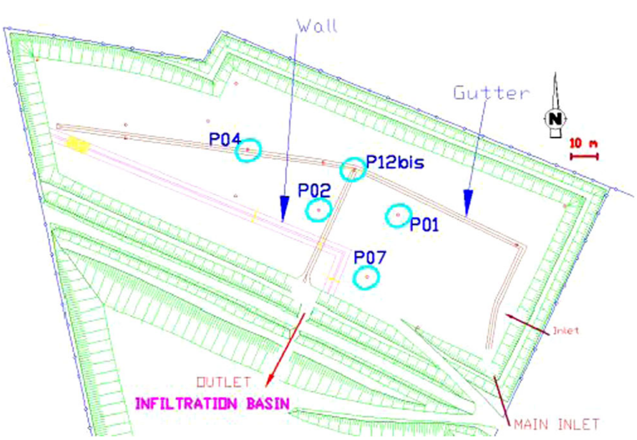


Fig. 2 Locations of the sampling point in the detention basin

Chemical and physical analyses

The physical and chemical characterizations were performed in the framework of the CABRRES research project on sediment sampling. The detailed physical–chemical analyses and the methodology were formulated by Sebastián et al. (2013). In order to complement this study, the particle density was assessed with the NF P 94-054 standards (AFNOR 1991).

In this paper, the chemical and physical characterization of the sediments provided information on the levels of potentially toxic concentrations of each of the pollutants analysed in the samples.

Toxicity tests

The pertinence of the tests concerns the small number of samples and the sensitivity of organisms to the toxic effects of the sediments (Moura et al. 2007; Angerville 2010; Angerville et al. 2013; Becouze-Lareure et al. 2012). Therefore, four tests were performed on the sediments studied in a large detention basin, in order to analyse the spatial variation of ecotoxicological effects.

Liquid-phase Microtox® test (Vibrio fischeri)

This acute toxicity test was performed as per standard (ISO 11348, 2009). The protocol of the latter permits evaluating the inhibition of the luminescence of a suspension of the bacteria *V. fischeri* in comparison to a control, following their contact with a range of dilutions of an aqueous sample. The initial luminescence of the bacteria is recorded first before they are brought into contact with the sample and then after incubation periods of 15 and 30 min following the contact.

The bioassay with the bacteria *V. fischeri*, marketed at the beginning of the 1980s under the name Microtox® (developed by AZUR Environment) and then Lumistox® (developed by Dr. Lange), met with rapid success for detecting the toxic effects of effluents of domestic and industrial waste water treatment plants. The device used in the framework of our study was the Microtox® M500 luminometer.

The standard recommends performing the test on the filtrate at 0.45 μm of the sample to be tested. The dilution medium used was distilled water with salt at 20 g/L. The range of dilutions generally comprised eight dilutions of the filtrate to be tested. We used the dilution medium for the control (two tubes). This range was employed directly in the test tubes which were adapted to the luminometer used.

The results are most often presented in the form of EC50 (effective concentration inhibiting 50 % of the luminescence of the suspension of bacteria at the end of the test period).

Solid-phase Microtox® test

This test permits detecting acute toxicity linked to the particle fraction of the sediment. The material and the biological reagent (strain *V. fischeri*) are the same as those used for the test on the liquid matrix. The protocol applied for performing the test is that of standard ISO 11348 (2009), adapted by AZUR Environmental for the solid phase (AZUR Environmental 1998).

As with the "liquid-phase" test, the inhibitive effect on the luminescence of the suspension of *V. fischeri* is assessed in comparison to a control, following contact between the bacteria and a range of dilutions of the "solid phase" kept in suspension in the dilution medium (water with salt at 20 g/L). The luminescence of the bacteria was recorded before they were brought into contact with the sample and then again following an incubation period of 20 min.

The results are most often presented in the form EC50 (effective concentration inhibiting 50 % of luminescence of the bacteria suspension following the test period).

Rotifer test (Brachionus calyciflorus)

This test of chronic toxicity was implemented as per the indications of standard ISO 20666 (2007). Its marketing in the form of Toxkit as well as the sensitivity of the organism and its fast reproduction were featured among the criteria, leading to the choice of this test for studying the toxic effects of a sample.

This bioassay is used to determine the inhibition of the growth of a population of rotifers *B. calyciflorus* in comparison to a control, after the organisms have been brought into contact for 48 h with a range of dilutions of an aqueous sample.

The results are most often presented in the form EC50 (efficient concentration inhibiting 50 % of the growth of the population of the rotifer *B. calyciflorus* following the test period).

When toxicity is low, it is also possible to present the percentage of inhibition of the growth of a rotifer population with non-diluted effluent (100 %).

Ostracod test (Heterocypris incongruens)

This chronic toxicity test performed over 6 days was implemented in conformity with the instructions of standard ISO 14371 (2012). The general principle of this bioassay is based on the direct contact of the organism with the sediment or solid matrix to be tested, to which fixed volumes of algal suspension and the prepared dilution medium were added. A control performed on a reference sediment is used for comparison to assess the effect of the sample on the organisms. The test is carried out on six well microplates using one microplate per sample and a microplate for the control. The criteria of the effects are the mortality of the organisms and their growth in comparison to their initial size.

At the start of the test, the size is measured of a set of 10 organisms as a representative of the batch used for the test. Contact is ensured with 10 organisms per well for each microplate. The microplates are then incubated for 6 h according to the instructions of the standard. At this stage, a population of 60 organisms are used for the control, and 60 organisms are used for each sample tested. At the end of the test, the number of live organisms per well is counted.

The data is processed following a visual assessment (using a binocular magnifying glass) of the two effect criteria of the test (organism mortality and growth). Mortality is expressed as the average percentage of dead organisms at the end of the incubation period. For growth, we proceeded to calculate the average size of the organisms by test well and then evaluated for both the control and the sample the increase in size of the

Table 1 Significance thresholds of bioassays

	Brachionus calyciflorus (% effect)	*Vibrio fischeri* (% effect)	*Heterocypris incongruens* (adapt to the standard) (% effect)
Effect criteria	Reproduction	Luminosity	Growth size of the organisms tested
No effect	]−30 % to 30 %[	]−20 % to 20 %[	$\alpha > 0.05$
Significant inhibition	≥30 %	≥20 %	>0 % and $\alpha < 0.05$
Significant stimulation	≤30 %	≤20 %	<0 % and $\alpha < 0.05$

Significant threshold (α) was obtained from the statistical Wilcoxon test

Table 2 Results of the rotifer tests

	Growth %				
	10	25	50	75	100
P02-S	No effect 15 %	Stimulation −33 %	No effect 24 %	No effect 11 %	No effect −12 %
P02-I	Stimulation −44 %	Stimulation −42 %	Stimulation −65 %	Stimulation −47 %	Stimulation −39 %
P02-B	No effect 12 %	No effect 3 %	Inhibition 39 %	Inhibition 30 %	No effect 13 %
P01	No effect 20 %	No effect 20 %	Inhibition 37 %	Inhibition 37 %	Inhibition 34 %
P04	No effect 14 %	No effect 0 %	No effect −7 %	No effect 14 %	No effect 7 %
P07	No effect 12 %	No effect 0 %	No effect −27 %	– –	Stimulation −39 %
P12Bis	Inhibition 30 %	Inhibition 51 %	Inhibition 32 %	Inhibition 58 %	Inhibition 81 %

organisms of each well, in comparison to their average size at the beginning of the test.

As this test was not performed using a range of dilutions, we did not determine the EC50 value for the sample tested. The results are therefore expressed in a percentage of effects observed for the non-diluted sediment

Significance of the bioassay results

The significance thresholds of *V. fischeri* and *B. calyciflorus* specified in standard ISO 17616 (2008) were chosen for these two organisms.

Since the significance of the biological effects observed during the ostracod test was not standardised, a statistical analysis of the results was performed with the Wilcoxon test. This permitted comparing two populations in the light of one criterion (e.g. the growth of the size of the control population and the sample population). In the framework of this study, we considered that the biological effect was significant at a threshold of 5 % ($\alpha < 0.05$). It is noteworthy that this test does not use the values taken by the observations, but their ranks do not require an assumption of the probability distribution of observed values.

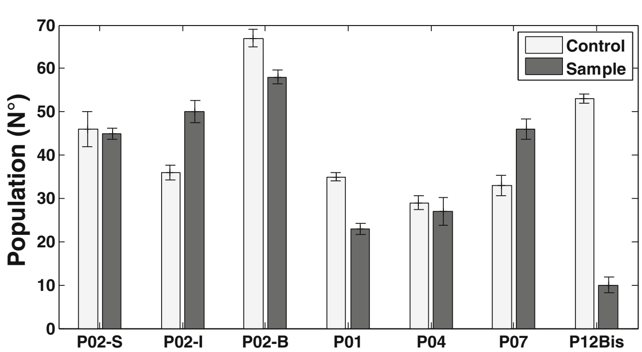


Fig. 3 Population by site compared with their control respectively

Table 1 summarises the significance thresholds chosen for the different bioassays.

Statistical analysis

Spatial variation

The spatial variation of the sediments in the detention basin allows studying the hydrodynamics of the particles in this structure. Spatial variation, in terms of significant differences, was assessed with the statistical Kruskal–Wallis test, which permitted comparing two or more samples (e.g. significant difference between the ecotoxicological effects of stored sediments on different zones of the detention basin). The Kruskal–Wallis test is a non-parametric test alternative to ANOVA, which assumes that the distributions of the measures of each sample are not normally distributed. In the framework of this study, we considered that the spatial variation was significant at a threshold of 5 % ($p < 0.05$), i.e. ecotoxicological effects are heterogeneous on the surface of the detention basin (Ruxton and Beauchamp 2008).

Principal component analysis

In order to show the role of the chemical and physical parameters that could explain ecotoxicological effects, a principal component analysis principal component analysis (PCA) (Kleinbaum et al. 1988) was performed with each variable measured on the surface of the detention basin. The ecotoxicological effect was represented by the percentage of inhibition.

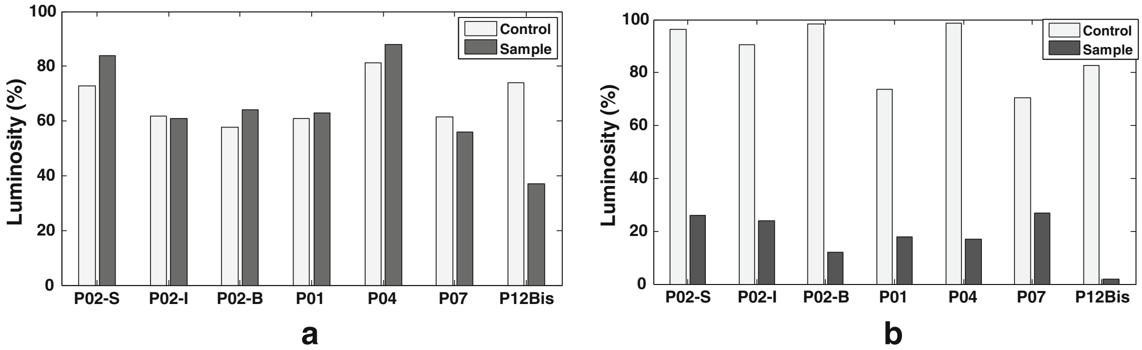


Fig. 4 **a** Luminosity of the interstitial water. **b** Luminosity of the raw sediments

Results

Spatial variation of ecotoxicity

The "Django Reinhardt" detention basin was rehabilitated in 2006. Thus, the sediments transported by storm water were stored in the basin bottom. In order to assess the toxicity of the sediments linked to spatial variation, the acute Microtox® tests and the chronic rotifer and ostracod tests were performed.

Chronic rotifer test (Brachionus calyciflorus)

Ecotoxicologically significant effects higher than 30 % are considered as inhibition factors for population growth, according to ISO 17616, 2008. Table 2 indicates the effects of the sediments on rotifer organisms for each concentration analysed. Figure 3 shows the variation in the reproduction of the organism in direct contact with sample (i.e. concentration to 100 %) and in the control (freshwater). This reproduction is represented by the population growth over 48 h.

The biological effects varied according to concentration (see Table 2) for each case studied. Regarding growth inhibition at concentrations up to 100 % (sample in direct contact with rotifers), the spatial variation of toxicity was significant from one point to another (Kruskal–Wallis test; $p=0.0005$, $p<0.05$). The variation of toxicity on the surface sediment was heterogeneous and also linked to the preferential deposit of the particles. The higher ecotoxicological effects were reflected at points P12Bis with a growth inhibition of 81 %.

The sediments from the three layers of site P02 analysed on a vertical profile were significantly different ($p=0.0065$). The sediments from the surface (P02-S) and bottom (P02-B) present a greater population growth inhibition at 50 % concentration than at 100 % concentration, whereas the middle P02-I presents growth stimulation for all the concentrations analysed.

Microtox® acute test (Vibrio fischeri)

Analysis of the biological effects of the Microtox® test focused on the calculation of EC50 (i.e. concentration for which biological effects are observed for 50 % of the individuals tested) and on the inhibition of luminescence (ISO 17616 2008).

Figure 4a, b shows the measurements of luminosity expressed in relative units for each point. The inhibition effect of the sample tested in the liquid phase after 30 min of exposure seems very low, compared with the inhibition effect of the sample tested in the solid phase. Regarding the liquid phase, the ecotoxicological effects of the surface sediments

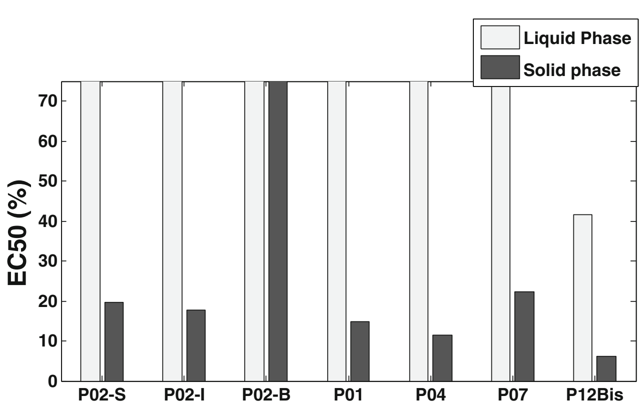


Fig. 5 EC50 of *V. fischeri* exposed to sediments in the solid phase (raw sediment diluted at 50 %) and in the aqueous phase (interstitial water)

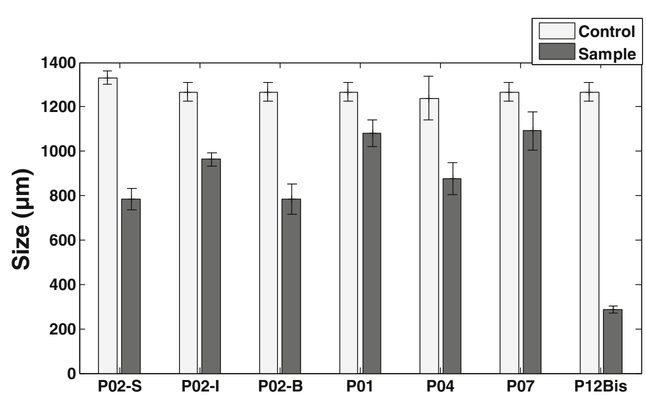


Fig. 6 Size of the organisms measured in the sampled sediments collected in the different sites, compared with their sediment control

Table 3 Chemical characteristics of the sediments stored in the Django Reinhardt detention basin

Points	Physical characteristics			Organic matter	Polycyclic aromatic hydrocarbons (16 PAHs[a]),	Heavy metals					
	Water content (TW) (%)	Particle sizes (D50) (µm)	Particles density (PD) (kg/m^3)	(% OM)	(ng/g)	Cadmium (Cd) (µg/g DM)	Chrome (Cr) (µg/g DM)	Copper (Cu) (µg/g DM)	Nickel (Ni) (µg/g DM)	Lead (Pb) (µg/g DM)	Zinc (Zn) (µg/g DM)
P02-S	43.4±0.8	57.8±7.5	2,349.5±224.4	17.7±0.5	1,750.3±218.8	3.1±0.3	158±15.8	280±28	97±9.7	127±12.7	1,534±153.4
P02-I	42.9±0.8	44.9±2.5	2,358.7±226.2	18.2±0.5	1,239.3±154.9	5.5±0.6	135±13.5	312±31.2	85±8.5	164±16.4	1,612±161.2
P02-B	46.9±0.8	47.7±1.6	2,396.3±233.2	13.8±0.4	1,268.4±158.6	9.3±0.9	192±19.2	310±31	125±12.5	325±32.5	1,766±176.6
P01	37.6±0.8	41.7±4.3	2,474.8±248.3	21.2±0.5	623.2±77.9	4.1±0.4	156±15.6	271±27.1	92±9.2	135±13.5	1,558±155.8
P04	41.1±0.8	33.8±2.3	2,459.8±245.4	25.5±0.6	900.2±112.5	5.6±0.6	137±13.7	308±30.8	81±8.1	201±20.1	1,663±166.3
P07	35.6±0.7	35.0±3.2	2,393±232.5	25.6±0.6	788.7±98.6	6.6±0.6	130±13	279±27.9	82±8.2	231±23.1	1,508±150.8
P12Bis	60.1±0.8	70.2±10.0	2,302.6±216.7	17.9±0.5	1,612.5±201.7	1.7±0.2	113±11.3	213±21.3	60±6	123±12.3	1,590±159

[a] Sixteen PAHs are the compounds proposed by US EPA as priority pollutants

seem very homogenous ($p > 0.05$). This result highlights the low effect of the sediments on the organism *V. fischeri* in the liquid phase. However, analysis of the solid phase shows a significant spatial variation (Kruskal–Wallis test, $p < 0.05$)

Figure 5 presents the EC50s obtained for the liquid and solid phases (raw sediment) of the sediments from each point. These results show that the solid fraction of the sediments is far more toxic for this organism than the liquid fraction of the same samples, a fact confirmed with luminosity. Therefore, the solid phase seems more sensitive to ecotoxicological effects.

Ostracod chronic test (Heterocypris incongruens)

The growth in size of organisms in direct contact with the sample compared to the control is shown in Fig. 6. The size of the organisms measured in the sediments studied is significantly smaller than that of the organisms measured in the control sample ($\alpha < 0.05$; Wilcoxon statistical test). Therefore, the ostracod test highlighted the ecotoxicological effect of the sediments analysed for the five zones of the surface detention basin.

The Kruskal–Wallis test highlighted the spatial variability of the ecotoxicological effect, with significant differences in the spatial distribution of toxicity ($p < 0.05$). The highest toxicity is located at point P12Bis. This point is situated in the oil separator which traps hydrocarbons and dry weather discharges. However, the ecotoxicological effects on the three thicknesses profiles analysed (surface, middle and bottom) are homogenous according to the Kruskal–Wallis test ($p > 0.05$). Accordingly, the preliminary results suggest that the toxicity distribution on the vertical profile (about 25 cm) of the stored sediments is invariable.

Ecotoxicological effects linked to chemical and physical characterisation

The pH values measured in the solid phase (between 6.7 and 7.9) and in the liquid phase (between 7.4 and 7.8) of the sediments were fairly homogeneous.

The results of the chemical analyses are summarised in Table 3. A detailed analysis is presented in Sebastián et al. (2013). In the present study, the chemical analyses contributed to explaining the ecotoxicological effects of sediments.

Figure 7a shows the variance explained by the first two components, given by their proportion of the total variance explained by this factor. The first two factors allow interpreting approximately 78 % (49 and 27 %, respectively) of the data on a cumulative basis. This PCA can be helpful for understanding the correlation between the ecotoxicological effects and the bio-physico-chemical characteristics of the sediments. For example, Fig. 7b shows that the results of the ostracod tests performed in the solid phase are strongly linked

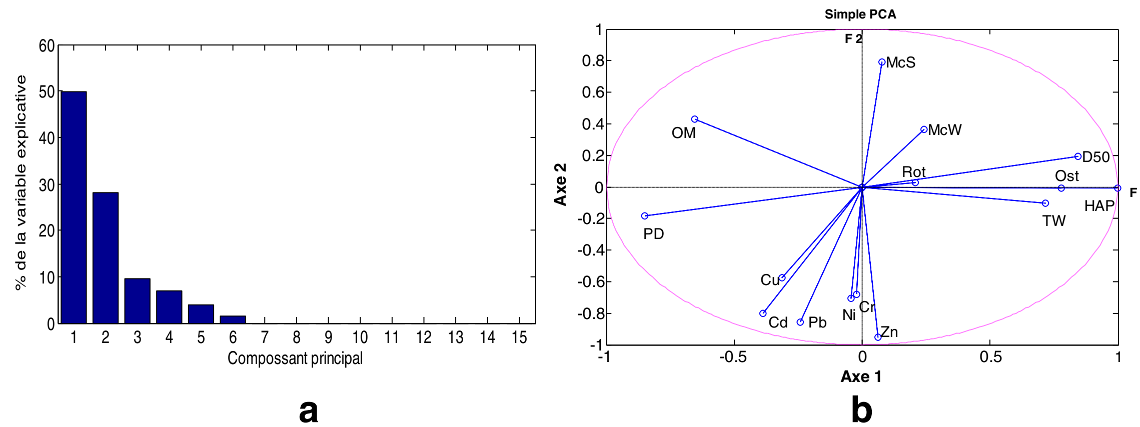


Fig. 7 **a** Eigenvalues and percentage of inertia explained by each component. **b** Correlation of the variables with components 1 and 2 (*circle* of correlations). *Rot* rotifer test, *McS* Microtox® test in solid phase, *McW* Microtox® test in liquid phase, *Ost* ostracod test

to the polycyclic aromatic hydrocarbon (PAH) contents of the sediments. Particle size and particle density (i.e. physical characteristics) also seem to be related to this toxicity. In addition, the role of sediment moisture must be taken into account.

Discussion

Ecotoxicity comparison of the liquid and solid phases

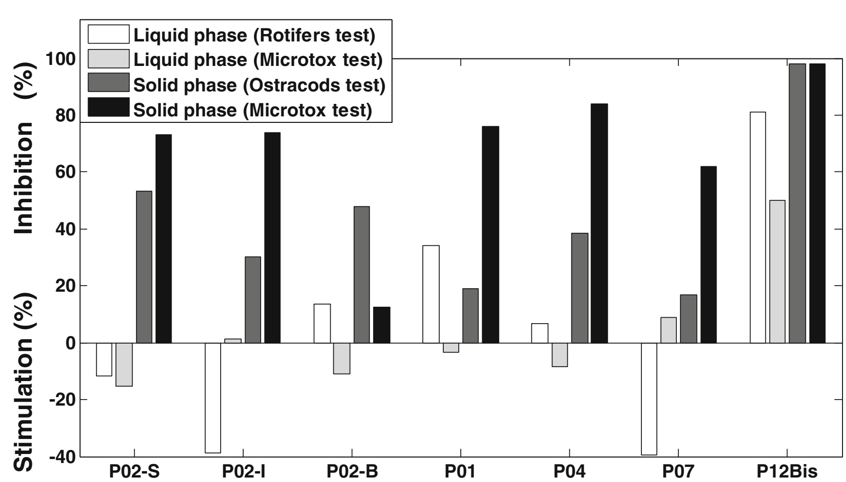
Figure 8 compares the ecotoxicological effects for the acute Microtox® test and the chronic rotifer and ostracod tests. Growth inhibition is compared in the solid phase (raw sediment) and liquid phase (interstitial water).

The effects of inhibition were clearly greater for the solid phase for all the samples analysed. This is consistent with several studies in which the particle fraction was observed to be the main vector of pollution in storm water (Matthews et al. 1997; Pitt 2003; Karlsson et al. 2010). These results validate the method proposed in preliminary works (Gonzalez-Merchan et al. 2013) which demonstrated the performance of solid-phase bioassays for assessing the toxicity of urban sediments.

Ecotoxicity of sediments

The battery of bioassays assessed in this study on five different sites at the bottom of a large detention basin, showed that point P12Bis presented significantly higher toxicity (see Fig. 8). This high ecotoxicity decreases the sustainable reutilisation of this sediment. The sediment from this point was taken in the oil separator which traps hydrocarbons and also receives dry weather discharges. At this point, the PAH concentration is high compared to the sites P01, P04 and P07 in the system. The oil separator seems to trap PAH, but not the metals. The other points are indeed more polluted in terms of metals. It is surprising to have a high concentration of PAH known to be mostly bound to particles and relatively low metal contents also known to be particulate. The specific hydrodynamic behaviour around this site, highlighting secondary currents (Yan et al. 2012), could contribute to explain

Fig. 8 Inhibition and stimulation effects on accumulated sediments



this selective dispersion of particulate pollutants and globally confirms the bad performance of the oil separator.

Moderate toxicity was identified for the other points (P01, P02, P04 and P07). These results differ from those obtained previously with water sampled from a combined sewer system (Angerville et al. 2013; Becouze-Lareure et al. 2012). Indeed, for the case mentioned above, the same type of ecotoxicity tests, particularly Microtox® and ostracod, highlighted far higher ecotoxicity values. This difference could be explained by higher concentrations of pollutants in the case of combined sewer systems (Angerville et al. 2013; Becouze-Lareure et al. 2012).

This fact seems to be consistent with the chemical analyses performed, which showed that concentrations of metals, PAH and PCB were higher for this basin than for the other cases. These pollutants could be part of the cause of the ecotoxicity measured. Thus, they can also be indicators of more global industrial pollution, involving other pollutants which were not addressed in the present study and could indicate illegal discharges. Previous works (Petavy et al. 2009) showed that up to 70 % of storm water sediments can be reused after physical treatment to decrease the toxic risks of urban sediments. Consequently, potential uses for these sediments may exist (e.g. road maintenance, filling material in urban environments and in the formulation of new products, etc.).

Conclusion

This study in the framework of the CABRRES project demonstrated the pertinence of spatial monitoring for detention basins by analysing the ecotoxicological characteristics of stored sediments. Our approach aimed at (1) improving knowledge on the characteristics of sediments in storm water discharges and their possible impact on receiving media (soil and/or water) and (2) improving the management of these systems in view to optimising sediment deposition and their lifespan.

The results showed that the ecotoxicity of accumulated sediments in storm water retention basins can be monitored using a relatively simple battery of bioassays adapted for this purpose. Bioassays were implemented for the solid phase (particle phase) and for the liquid phase (interstitial water) of sediments. The "ostracod" test was used in the solid phase (raw sediment), whereas the "rotifer" test was used in the liquid phase (interstitial water), and the "Microtox®" test was used in both phases. The results demonstrated the pertinence of ecotoxicological assays in the solid phase, given the sensitivity of these bioassays and the low quantity of sediment necessary for their implementation. They also showed the relationship between the physical and the chemical characteristics of the sediments on one hand and their ecotoxicity on the other.

The results also showed that the ecotoxicological effect of the sediments at the bottom of a large system is heterogeneous and much more considerable in often flooded areas, in particular in the oil/water separator (point P12Bis). Accordingly, this study raises the question of the implementation of this type of facility in detention basins.

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