Stormwater infiltration practices in urban area: influences on groundwater ecosystems

L'infiltration des eaux pluviales en milieu urbain : conséquences sur l'écosystème aquatique souterrain

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RÉSUMÉ

L'urbanisation induit une imperméabilisation des sols et une augmentation du ruissellement, réduisant ainsi la recharge de la nappe souterraine. La gestion des eaux de pluie consiste à les collecter et les infiltrer vers la nappe qui est protégée de la pollution par des processus auto-épurateurs localisés dans le sol et la zone insaturée. Les dynamiques de la matière organique et des micro-organismes ont été suivies dans les eaux de surface et les eaux souterraines en amont et en aval des trois systèmes d'infiltration (SI). Les teneurs en Carbone Organique dissous (COD) biodégradable et réfractaire ont été mesurées sur l'eau et la croissance des biofilms a été suivie à l'aide des substrats artificiels incubés dans le milieu. Le COD diminue fortement au cours de l'infiltration, mais sa fraction biodégradable demeure plus forte en aval de SI, tout comme les biofilms qui sont stimulés par les infiltrations en biomasse et en diversité.

ABSTRACT

Urbanization increases impervious surfaces and stormwater runoff reducing groundwater recharge. Stormwater management mainly consists in the collection of rain water and its infiltration to the aquifer, which is protected by the self-purification capacity of the soil and the unsaturated zone. The dynamics of organic matter and micro-organisms were studied in surface water and in groundwater upstream and downstream of three stormwater infiltration systems (SIS). Dissolved Organic Carbon (DOC) concentrations were measured in surface and in ground waters, while biofilm dynamics were studied using artificial substrates incubated in the waters. DOC sharply decrease from surface water to the groundwater, but the biodegradable fraction of DOC was higher downstream than upstream of the SIS and the biofilms were stimulated by the infiltration for both biomass and bacterial diversity.

MOTS CLÉS

Groundwater ecology, Infiltration basins, Micro-organisms, Organic matter dynamics, Stormwater infiltration practices,

1 INTRODUCTION

Urban areas host half of the world's population (80% in France and in most of industrialized countries), and this proportion is predicted to increase by 2030 (United Nations 2007). One of the major landscape modifications associated with urbanization is an increase in the impervious surface coverage. The sealing of urban surfaces alters the natural water cycle by increasing stormwater runoff during rainfall events thereby generating urban flooding and reducing groundwater recharge (Marsalek and Chocat 2002). In this context, stormwater management practices, mainly based on the collection and the infiltration of stormwater from basins to groundwater, have been developed for 30 years. However, the environmental efficacies of these stormwater infiltration systems (SIS) rely exclusively on the self-purification capacity of soils and aquifers. The performance of SIS to prevent groundwater contaminations by the most common urban contaminants like hydrocarbons and heavy metals has been demonstrated (Datry et al. 2004) but more research is needed to evaluate the transfer of other organic matter compounds from surface to the aquifer and its consequences on groundwater ecosystem functioning. Therefore, the aim of the present paper was to evaluate the influences of stormwater infiltration practices on groundwater ecosystems by studying the dynamics of organic matter in three SIS. Due to the main importance of organic carbon availability for groundwater microbial communities (Foulquier et al. 2010), we also aimed to determine how carbon dynamics in SIS may influence micro-organisms in the aquifer.

2 MATERIAL AND METHODS

2.1 Stormwater infiltration systems (SIS)

The experiments have been performed in three SIS of the conurbation of Lyon (France) characterized by a vadose zone thickness < 3 m and presented in details in Voisin et al. (2018): IUT= Campus of the University Lyon 1, MIN = Minerve, and GB = Grange Blanche. Each SIS consisted in a settling and an infiltration basin that collected stormwater from residential, commercial, agricultural and/or industrial areas. Each SIS is equipped with wells located upstream and downstream of the infiltration basin. The upstream well was used for sampling groundwater not impacted by stormwater infiltration whereas the downstream well allowed the sampling of impacted groundwater (Figure 1). Clay beads were also incubated during 10 days in these wells for the collection of biofilms (attached bacteria) in the aquifer (Voisin et al. 2016, Mermillod-Blondin et al. 2019).

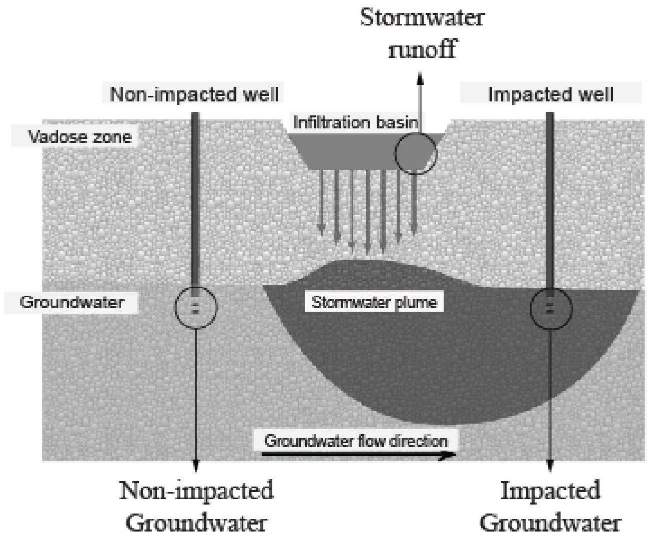

Figure 1: Positioning of sampling/incubation points in each stormwater infiltration system

Additionally, runoff water collection tanks were placed at the entrance of infiltration basins. They were used to collect water during rainfall events but also for the incubation of clay beads. All samples and clay bead incubations were performed in triplicates for each point.

2.2 Organic matter dynamics and microbial analyses

The transfers of dissolved organic matter from the surface of the basin to the aquifer was evaluated by measuring the concentrations of total and biodegradable fractions of dissolved organic carbon in waters collected in infiltration basins and in wells during rainfall events. Dissolved organic carbon (DOC) concentrations were measured on filtered water samples (0.45 µm, HAWP Whatman filters) with a multi N/C ® 3100 device (Analytik Jena, Jena, Germany). Biodegradable DOC (BDOC) was determined by the Servais' method.

Microbial analyses were performed on clay beads incubated during 10 days in infiltration basins and wells of the three SIS during rainfall events. Microbial biomasses of biofilms developed on clay beads were assessed from Lowry's total protein assays. Total proteins were measured using the Sigma Protein Assay Kit P-5656 (Sigma Diagnostics, St Louis, MO, USA). Hydrolytic activity of biofilm was estimated using the fluorescein diacetate (FDA) hydrolysis method (Voisin et al. 2016). The 2-(p-iodophenyl)-3-(p-nitrophenyl)-5-phenyl tetrazolium chloride (INT) was used to measure dehydrogenase activity (respiratory activity) following Voisin et al. (2016). To determine the diversity of bacteria (of Operational Taxonomic Units –OTUs-) developed on clay beads using DNA analyses, microbial cells were detached from beads by shaking at 2500 rpm for 2 minutes in 10 mL of 0.8 % NaCl. A 0.22 µm filtration was performed to retrieve cells and aggregates. DNA was extracted from filters using the FastDNA spin kit for soil (MP Biomedicals France). For clay beads, the amount of extracted DNA was quantified by spectrophotometry using a ND1000 Nanodrop (Thermo Fisher Scientific, USA). The sequencing and bioinformatics analyses were performed following the procedure described in Voisin et al. (2018).

2.3 Statistical analyses

For each experiment, chemical (DOC and BDOC) and microbial (biofilm proteins, activities, number of bacterial species –OTUs-) analyses were compared among water types (stormwater runoff, impacted and non-impacted groundwaters) using a mixed model with water type as fixed factor and SIS as random factor. To evaluate the relationship between chemical variables and biofilms, Pearson's correlations were computed to determine the relation between DOC and BDOC and clay bead biofilm variables (i.e. biomass and diversity). For all variables, the normality and the homoscedasticity of the residues were tested using the Shapiro-Wilk's test and the Bartlett's test, respectively. When these assumptions were not met, data were Ln transformed before statistical analyses. Statistical tests were performed using the R software (R Development Core Team 2008).

3 RESULTS AND DISCUSSION

DOC concentrations sharply decreased from surface (range of DOC concentrations: 4.1 to 5.8 mg/L) to the aquifer (range of DOC concentrations: 1.2 to 2.0 mg/L) for the three SIS. This pattern was largely due to the retention of BDOC which was more than 75% for the three SIS, whereas the retention of refractory DOC (total BDOC – BDOC) was more variable and globally less important (from 18% to 61% depending on SIS). The present study demonstrated that processes (mineralization and/or sorption processes, Shen et al. 2015) occurring in soil and vadose zone of SIS were efficient enough to limit DOC fluxes to the aquifer. Nevertheless, we also measured enrichments of BDOC concentrations in infiltration-impacted groundwater in comparison with non-impacted groundwater for the three SIS (Figure 2a, mixed model, "water type" effect, $p < 0.05$). Such enrichment had significant influence on the microbial biofilm developed on clay beads as protein content, hydrolytic and dehydrogenase activities measured on biofilms were significantly higher for clay beads incubated in infiltration-impacted groundwater than in non-impacted groundwater for the three SIS (Figure 2b, mixed model, "water type" effect, $p < 0.05$ for microbial biomass and activities). This stimulating effect of infiltration was more likely associated with the enrichment of groundwater with available organic matter (Pearson's linear correlations between BDOC and microbial variables measured on clay beads, $R^2 > 0.5$, $p < 0.05$). Thus, in groundwater ecosystems limited by C availability, the microbial biofilm was a good indicator of aquifer trophic conditions and our clay bead incubation procedure may be highly efficient for monitoring these conditions (Mermillod-Blondin et al. 2013).

Our results also showed that the bacterial diversity of biofilms developed on clay beads was higher in infiltration-impacted groundwater than in non-impacted (Figure 2c, "water type" effect, $p < 0.05$ for the number of OTUs recovered from clay bead biofilms). In parallel with BDOC enrichment of infiltration-impacted groundwater, these results clearly supported the species-energy theory (Wright 1983) stating that species richness correlates positively with energy sources (organic cabon availability in the present study).

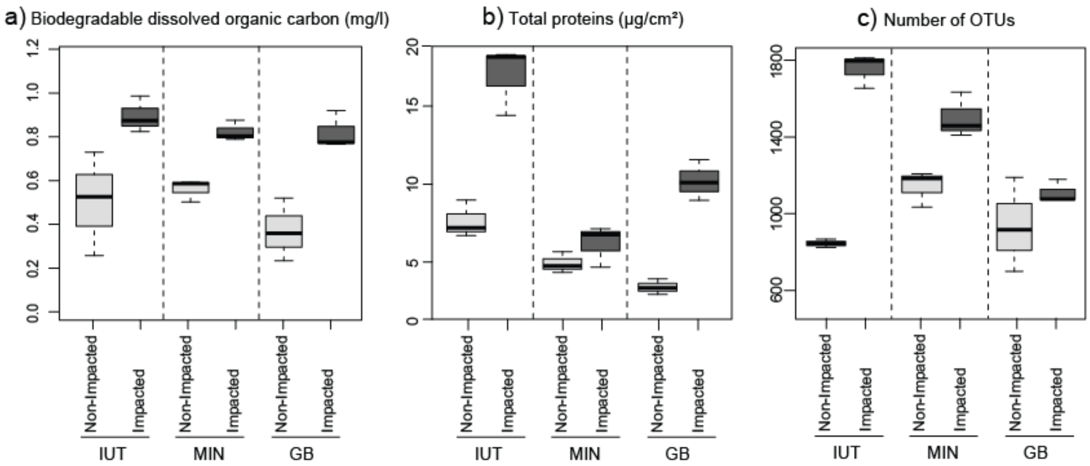

Figure 2: a) Biodegradable dissolved organic carbon (BDOC), b) total proteins measured on clay beads, and c) number of bacterial OTUs measured on clay beads for non-impacted and infiltration-impacted groundwaters in the three SIS

4 CONCLUSION

In addition with water input, the enrichment of MO due to stormwater infiltration had an impact on micro-organisms and trophic conditions in groundwater. One perspective of these results would be to evaluate whether changes in microbial diversity due to stormwater infiltration practices were associated with the growth of pathogens and potential health risks. Similarly, more specific analyses on DOC quality are also needed to better understand their potential impact on groundwater quality and ecology.

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