Indicator bacteria variation in separate sewer systems in Östersund, Sweden - Preliminary results

La variation des indicateurs bactériens et des flux de MES dans les systèmes séparatifs d'eaux pluviales à Östersund, en Suède - Résultats préliminaires

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RÉSUMÉ

Les bactéries fécales constituent un risque majeur de pollution de masses d'eau destinées à des usages multiples, notamment comme sources d'eau potable ou à des fins récréatives. Si les rejets d'eaux pluviales peuvent contribuer de façon significative à la pollution microbiologique, on ne les a pas étudiés dans leur intégralité au niveau européen. Nous avons étudié la présence de bactéries indicatrices de contamination ainsi que les matières en suspension (MES) totales dans les eaux pluviales rejetées par quatre bassins versants urbains, avec des superficies allant de 5 à 40 ha, à Östersund, en Suède. L'objectif était de déterminer la variation locale des souches bactériennes standards et des MES totales dans des bassins versants urbains en Suède avec des occupations du sol particulières. Les variations intra-événement ont également été étudiées. Par temps sec, les concentrations en bactéries indicatrices de contamination dans les collecteurs transportant le débit de base ne dépassent pas les 100 CFU/100 mL. Par temps de pluie, les concentrations totales en coliformes et en entérocoques intestinaux ont été multipliées par un facteur de 10^2 à 10^3 par rapport à celles du débit de base. Par rapport à ces deux paramètres, des concentrations beaucoup plus faibles ont été observées pour E. coli et C. perfringens. Les concentrations bactériennes diffèrent considérablement d'un site de prélèvement à l'autre et un effet partiel de premier flot a été observé. Des corrélations significatives entre le total des MES et les bactéries indicatrices de contamination ont été observées de façon partielle. Celles-ci sont spécifiques aux bassins versants et nécessitent une évaluation plus détaillée. Des recherches plus approfondies se concentreront sur les variations saisonnières et les facteurs influents.

ABSTRACT

Faecal bacteria are a major pollution threat of water bodies designated for multipurpose use including drinking water sources or recreational purposes. Even though stormwater discharges may contribute significantly to microbiological pollution, they have not been fully investigated in the European context. We have studied the presence of indicator bacteria and total suspended solids (TSS) in stormwater discharged from four urban catchments, with areas between 5 and 40 ha, in Östersund, Sweden. The aim was to determine local variation of standard bacteria strains and TSS in Swedish urban catchments with specific land uses. Further, intra event variations were investigated. During dry weather, indicator bacteria concentrations in sewers conveying baseflow did not exceed 100 CFU/100 mL. During storm runoff, total coliform and int. enterococci concentrations increased 10^2 to 10^3 times, compared to those in baseflow. Compared to these two parameters, considerably lower concentrations were observed for E. coli and C. perfringens. Bacteria concentrations differed significantly among the sampling sites and partly, a first flush phenomenon was observed. Partly, significant correlations between TSS and indicator bacteria were observed. These were catchment specific and need a more detailed assessment. Further research will focus on seasonal variations and influential factors.

KEYWORDS

Indicator bacteria, Local variation, Separate sewer, Stormwater quality, TSS

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1 INTRODUCTION

The microbial assessment of stormwater by indicator bacteria is an important measure addressing the presence of pathogen bacteria in receiving waters. Most concerns are due to animal and human faeces in the water phase which are a source of human pathogens and bacteria and cause high oxygen demand in the receiving environment. Major faecal pollution sources in urban areas are the natural environment (soil, water), animal faeces, organic waste and wastewater (Butler and Davies, 2011). Pollutant sources and rates depend *inter alia* on the degree of development, land use type, wildlife presence, farming and recreational activities, sewer system characteristics (Olyphant et al., 2003; Jeng et al., 2005; Coulliette and Noble, 2008; Rowny and Stewart, 2012). Thus pollutant build-up and wash-off varies significantly between different urban (sub-)catchments and geographical locations due to variable hydrogeological parameters and availability of pollutants specific for each land use area and activity (Brezonik and Stadelmann, 2002; Ghafouri and Swain, 2005; Tiefenthaler et al., 2011). Assessing different catchment types and development degrees, some studies have shown clear pollution trends due to spatial variability indicating that urbanized catchments exhibited higher faecal bacteria concentrations than catchments dominated by grasslands (Desai and Rifai, 2010; Tiefenthaler et al., 2011). Several studies have shown indicator bacteria and TSS concentrations increases compared to dry weather flows during and after stormwater discharges to the receiving waters, when wet-weather concentrations are considerably higher than during dry periods (Gannon and Busse, 1989; Dutka and Marsalek, 1993; Jeng et al., 2005; Salmore et al., 2006; Coulliette and Noble, 2008). Furthermore significant correlations were observed between indicator microorganisms and TSS loads during wet weather flows (Olyphant et al., 2003; Jeng et al. 2005; Coulliette and Noble, 2008).

However most studies draw their conclusions mainly based on grab sampling in natural water bodies, thus only examining the receiving water’s response to stormwater runoff and not the stormwater characteristics themself. Due to dilution and bacteria decay related to sedimentation and ambient conditions in the receiving environment, it could often not be clearly stated in which degree the actual stormwater was polluted. Studies investigating stormwater quality are based mainly on time weighted composite or grab sampling (Mallin et al., 2000; Selvakumar and Borst, 2006) and therefore flow weighted load discharges and intra-event variations are hard to assess.

Some recent studies evaluated bacteria variation in urban stormwater systems by flow weighted averages (McCarthy, 2009; Hathaway and Hunt, 2011; McCarthy et al., 2012) concluding that small-scale variability of bacteria and TSS seem to be affected rather by land-use characteristics than climatic or hydrological parameters. However the impact of land use types within specific catchments was poorly evaluated regarding standard complementary indicator bacteria strains, since local variation was assessed by the commonly used faecal indicators from the same strain, faecal coliforms and *E. coli* (McCarthy, 2009; McCarthy et al., 2012; Rowny and Stewart, 2012). Moreover most previous studies on the topic were carried out in Canada, US and Australia; there is a lack of studies investigating bacteria variation in stormwater runoff in Europe and especially for Northern-Europe conditions where cold temperatures and alternating sunshine conditions may have an impact on bacterial transport and survival. Since the survival of faecal coliforms including *E. coli* is highly dependent on e.g. ambient conditions like temperature, moisture, sun radiation (Van Donsel et al., 1967; McFeters and Stuart, 1972) the simultaneous assessment with more persistent indicator strains, like int. enterococci and *C. perfringens* could be useful when monitoring faecal bacteria fluxes in stormwater in temperate to cold climate conditions. The aim of the present study is to assess local variation of standard indicator bacteria strains and TSS in Swedish urban areas with specific size and land use types ranging from undeveloped land to downtown catchments. Furthermore the intra-event variation of selected indicator bacteria and its correlation with TSS will be evaluated in spatial context relying on flow weighted, manual sampling.

2 METHODS

2.1 Study area description

The data presented in this paper was collected from storm sewer manholes close to their outlets. Four urban catchments were selected situated in the vicinity of the drinking water plant and beach areas in Östersund, Sweden. Östersund is located in the central part of Sweden at latitude 63° 11’ N and longitude 14° 30’ E with altitudes between 300-380 m above sea level. The selected study catchments are drained by separate storm sewers with outlets into Lake Storsjön, the fifth largest lake in Sweden (area: 464 km^2). The lake is a source for drinking water supply for around 50,000 inhabitants (16-17 million l/d) and also serves for recreational purposes.

The four evaluated catchments Odenbacken, Tjalmargatan, Beijers and Lasarettet vary in area from 5 to 40 ha. In the southern part of the city two catchments were investigated; Odenbacken, a green, less-developed catchment mainly used for recreational activities, and Tjalmargatan, a residential catchment with around 50% imperviousness. The two other catchments are situated in the central part of the city north of the drinking water plant; Beijers, a large central catchment with central buildings, residential and campus areas and around 60% imperviousness and Lasarettet, a small central catchment dominated by the hospital buildings and facilities with around 80% imperviousness. The catchment characteristics are presented in Table 1.

Table 1. Sampling site and catchment characteristics

Catchment name	Catchment type	Area (ha)	Imperviousness (%)	Baseflow	No. of samples
Odenbacken	Green recreational	20	35	No	30
Tjalmargatan	Residential	20	50	Yes	34
Beijers	Central large	40	60	No	21
Lasarettet	Central small	5	80	Yes	23

2.2 Sampling procedure

During three small to moderate storm events in September and October, 2012, discrete water samples (appr. 1 L) were collected manually from the same sampling point. Storm events were sampled whenever 2 mm or more rainfall occurred after at least three antecedent dry days. All four sampling sites were equipped with area velocity flow meters to allow flow weighted sampling. Manual discrete samples were taken by dipping 2 L polypropylene bottles directly in stormwater runoff, and rinsing the bottles between each sample with distilled water. In total 108 samples were collected during the rain events and 16 baseflow samples during dry periods. Between these individual storm events, baseflow samples were taken in the two catchments conveying dry-weather flow (Tjalmargatan and Lasarettet). Rainfall and temperature measurements were carried out to assess climate conditions during sampling events with a tipping bucket and a temperature logger installed in the city center (Table 2).

Table 2. Climate data for Östersund city centre

Storm	Ave. Temp	A. dry days	Tot. Rain	R. Intensity	R. Duration
14.09	9.5°C	14	3.2 mm	3.2 mm/h	1 h
26.09	7.5°C	9	2.8 mm	0.4 mm/h	7 h
04.10	10.5°C	6	6 mm	4.6 mm/h	1.5 h

2.3 Selected parameters and analysis methods

The four indicator bacteria groups total coliforms, *E. coli*, int. enterococci, and *C. perfringens* and TSS have been selected for simultaneous sampling and study purposes. The first three bacteria groups are implemented in the European and Swedish drinking water regulations concerning drinking water quality standards. Additional monitoring of *C. perfringens* is required for drinking water originating from surface waters (98/83/EC; SLVFS 2005:10). TSS and total coliforms monitoring is also implemented in the European regulations for raw surface water quality (75/440/EEC), whereas E. coli and int. enterococci is used by the assessment of bathing water quality (76/160/EEC).

After sample collection the water samples for bacteria analyses were preserved in cooling boxes at <5°C. Both bacteria and TSS sample analyses were performed within 12 h of sample collection. All bacteria samples were analyzed at an accredited laboratory using membrane-filtration following international standard methods (ISO 8199:2005). Bacteria colonies were counted after 48 h incubation time at 35°C for total coliforms and 44°C for *E. coli* and int. enterococci respectively (SIS 28167:1996; ISO 9308-1:2000b; ISO:7899-2:2000c). *C. perfringens* colony units were counted after 24 h incubation time at 44°C under anaerobic conditions (ISO:6461:2:1986). The detection interval for indicator bacteria was 10-300,000 CFU/100 mL with 35% uncertainty for total coliforms and *E. coli* respectively. Same detection intervals and a measurement uncertainty of 30% applied for int. enterococci, whereas the lower detection limit for *C. perfringens* was 1 CFU/100 mL with a 50% uncertainty. TSS were analyzed by standard methods at the local accredited laboratory, filtered through a previously weighed glass fibre filter (Whatman GF/A filter), dried at 105°C for at least 1 h and weighed again (SS-EN 872:2005) with lower detection limit of 5 mg/l and 15% uncertainty.

3 RESULTS AND DISCUSSION

3.1 Local variation of indicator bacteria and TSS

Indicator bacteria and TSS concentrations varied significantly between study sites and within the storm runoff events. In Table 3 the arithmetic means of all events, their standard deviation, and min. and max. concentrations are presented. Site mean concentrations (SMC) were calculated by flow weighted average concentrations, baseflow mean concentrations (BMC) by arithmetic means of baseflow samples.

During dry weather periods, TSS concentrations were very low not exceeding 10 mg/L in the residential and small central catchments conveying baseflow. During the sampled storm events 10 to 20 times higher TSS concentrations were observed with max. concentrations between 147-281 mg/L. SMC during storm runoff were highest in the stormwater from the two central catchments with TSS means of 58 mg/L in the smaller and 73 mg/L in the larger central catchment, respectively. The SMCs of TSS in the residential and green catchments were similar. The highest variation between samples for all events was observed in the residential site with TSS values between <5 - 238 mg/L and a standard deviation of 69 mg/L.

Total indicator bacteria in the two catchments conveying baseflow were below 100 CFU/100 mL. In the stormwater runoff total coliform and int. enterococci concentrations were between 10^2 and 10^3 times higher compared to the concentrations in the baseflow. Considerably lower concentrations were observed for the other two indicators ranging between 10 and 23,000 *E. coli* and 6 to 550 *C. perfringens* respectively. The green recreational catchment and the large central catchment showed comparably high SMC´s for total coliforms with mean concentrations of 22,700 CFU/100 mL and 23,500 CFU/100 mL respectively. *E. coli* and int. enterococci levels were highest in the large central catchment with SMC`s of 6,800 CFU/100 mL for *E. coli* and 18,100 CFU/100 mL for int. enterococci respectively. Although low *C. perfringens* concentrations were detected in the stormwater at all four sites compared to other indicator bacteria varying between 145 and 220 CFU/100 mL, the resulting SMC were up to 100 times higher than the BMC. The highest variations within all total coliform samples were observed at the green site, followed by the large central site with 31,000 CFU/100 mL and 25,900 CFU/100 mL standard deviation and min. to max. values between 1,000 and 140,000 CFU/100 mL and 1,000 and 110,000 CFU/100 mL respectively. E. coli and int. enterococci variation was highest in the two central catchments.

Compared to the actual European and Swedish bathing water, raw water and drinking water regulations, these findings support the assumption that stormwater runoff can contribute to the impairment of receiving waters designated for raw water withdrawal and recreational purposes. The European bathing water directive defines bacteria concentrations that indicate a sufficient bathing water quality by 900 CFU/100 mL for *E. coli* and 330 CFU/100 mL for int. enterococci, based upon a 90-percentile evaluation of normal probability density monitored by at least 3 samples per bathing season (76/160/EEC). The recommended values for surface water intended for the abstraction of drinking water are 50 CFU/100 mL for total coliforms and 25 mg/L for TSS (75/440/EEC) whereas according to the drinking water regulations none of the indicator bacteria should be detectable in drinking water (98/83/EC). Since bacteria discharge into receiving waters is followed by immediate die-off processes due to sedimentation and ambient physical and chemical conditions, preceding assessment of bacterial fluxes in the actual stormwater runoff can lead to a fair estimation of microbiological contamination induced by storm discharges.

Although total coliform concentrations were highest in both the large central catchment (Beijers) and the less developed green catchment (Odenbacken), TSS concentrations were highest in the large central catchment and lowest in the less developed green catchment, meaning that indicator bacteria does not necessarily follow TSS patterns. The same pattern has been previously reported for TSS (Brezonik and Stadelmann, 2002) but the highest total coliform concentrations were not necessarily associated with undeveloped, recreational catchments as shown by previous studies (Couliette and Noble, 2008; Tiefenthaler et al., 2011). *E. coli* and int. enterococci levels were highly variable in the runoff from the central catchments, suggesting higher and varying faecal sources in more developed catchments. Similar concentrations as found in this study were reported by Selvakumar and Borst (2006) and Hathaway et al. (2010) for int. enterococci. In contrast *E. coli* concentrations were found to be much lower in the present study for all catchments. Reported mean concentrations for *E. coli* were in general 10 times higher during fall compared to the present findings relaying on similar sampling period of the year (Desai and Rifai, 2010; Hathaway et al., 2010). The considerably lower average temperatures during this period of the year might explain the low E. coli levels during fall, since (in comparison to int. enterococci) E. coli has a lower resistance against ambient conditions i.e. air and water temperature, land cover and sun exposure (McFeters et al., 1974).

Table 3. Site-specific statistics for TSS (mg/L) and indicator bacteria (CFU/100 mL)

Green recreational	**Mean**	**St. Dev.**	**Max.**	**Min.**	**SMC**	**BMC**
TSS	41	30	147	8	46	-
T. coliforms	19 104	31 060	140 000	1 000	23 471	-
E. coli	400	349	1 050	10	423	-
Int. Enterocci	2 519	2 029	9 000	310	2 453	-
C. perfringens	214	231	550	24	207	-
Residential						
TSS	57	69	238	3	47	<5
T. coliforms	12 522	14 245	55 000	80	10 878	67
E. coli	30	292	910	20	305	13
Int. Enterocci	2 988	2 474	10 000	540	2 923	<10
C. perfringens	130	75	220	6	145	1
Central large						
TSS	87	65	281	21	73	-
T. coliforms	18 059	25 922	110 000	1 000	22 697	-
E. coli	6 185	7 661	23 000	530	6 784	-
Int. Enterocci	19 176	16 938	60 000	2 000	18 148	-
C. perfringens	239	88	400	95	223	-
Central small						
TSS	58	37	170	4	58	5
T. coliforms	6 966	16 314	80 000	50	8 793	<10
E. coli	847	1 621	8 000	30	1031	12
Int. Enterocci	2 302	6 089	30 000	120	2 531	<10
C. perfringens	210	93	400	45	179	3

3.2 Intra-event variation of indicator bacteria and TSS

The variations within events showed different patterns for the three catchments for both indicator bacteria and TSS. Similar variations were observed in the less developed green catchment and small central catchment, with higher TSS loads during initial runoff (first flush). During all the three sampled events more than half of the total TSS load was transported with the initial 30 to 40% of the total event runoff. The two other catchments showed no clear trend, with different patterns between sampled events; for some events a first flush was observed, while at others concentrations were rather constant during the whole event.

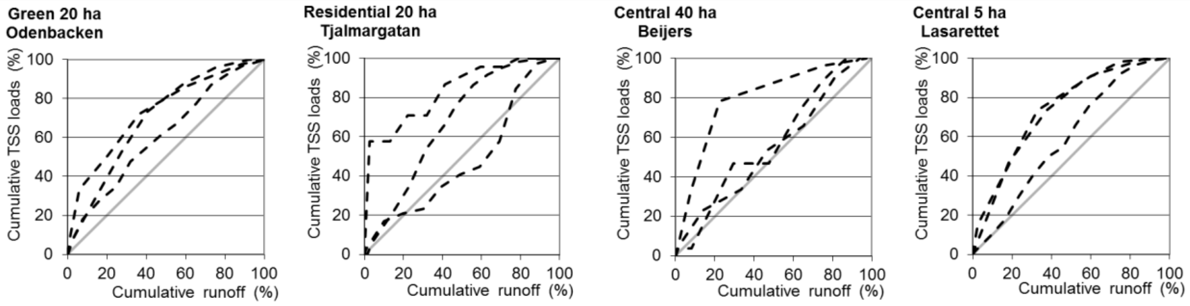

Fig. 1: Local variation of cumulative TSS loads to cumulative runoff volume (dashed line) for all three events

Similar to TSS, total coliform variations in the less developed green catchment showed a first flush; the same trend was detected in the large central catchment. In both catchments, during all three sampled events more than half of the total coliform load was transported with the initial 30 to 40% of the total event runoff. *E. coli* showed the same trend between events with slightly lower initially accumulated loads than total coliforms. Total coliform and *E. coli* variations were highest in the two other catchments, the residential and small central catchments indicated load extremes preceding or exceeding peak flows and with no clear trend between sampled storm events.

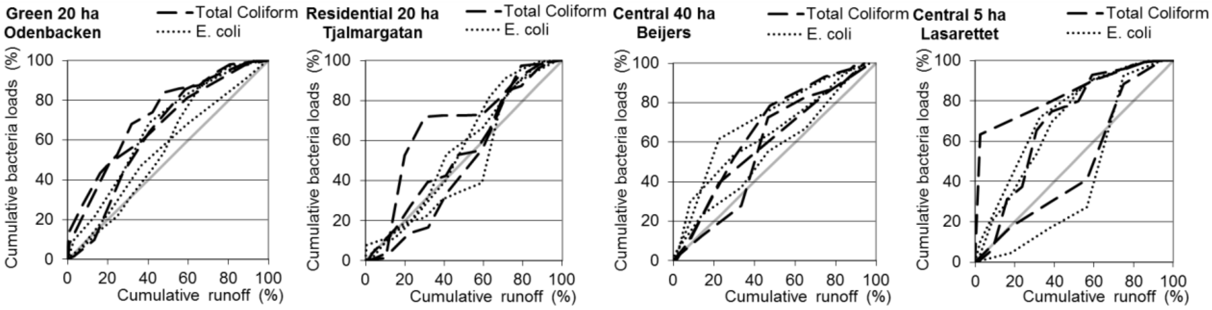

Fig. 2: Local variation of cumulative total coliforms (dashed line) and *E. coli* (dotted line) loads to cumulative runoff volume for all the three events

Int. enterococci and *C. perfringens* patterns between sites were quite similar to the two other indicator bacteria. Highest variations of int. enterococci and *C. perfringens* followed the pattern of other indicator bacteria and were related to the residential and small central site.

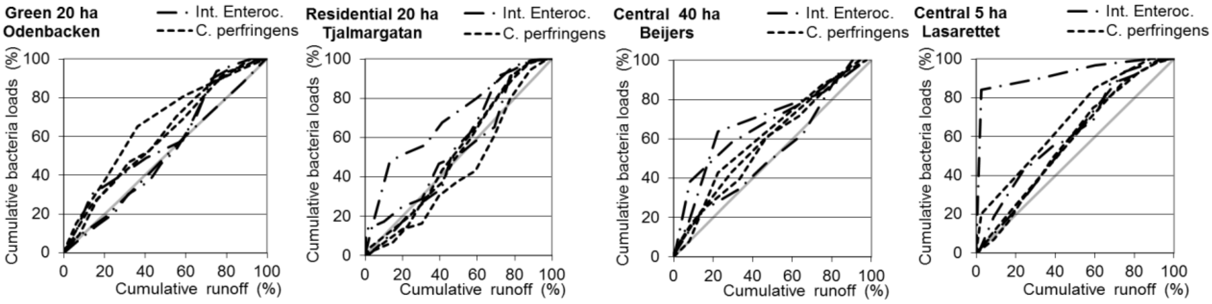

Fig. 3: Local variation of cumulative int. enterococci (dotted-dashed line) and *C. perfringens* (dashed line) loads to cumulative runoff volume for three events

Similar patterns for all sampled events were observed for TSS and total coliforms in the green catchment with higher initial loads during storm events. Furthermore similar variation patterns for the same constituents were observed between the green catchment and the large central catchment with slightly lower initial loads in the latter. In the residential and small central catchment no comparable trends were observed between events for most of the constituents. An explanatory factor might be the presence of baseflow in the residential and small central catchments. In contrast to the two other catchments this can impact the variability of storm runoff by dilution. Another factor might be the high percentage of roof areas within the residential and small central catchments (where impervious surfaces are dominated by hospital roofs). Due to the high percentage of roof surfaces stormwater constituents from these catchments are more affected by rainfall characteristics, i.e. rain intensity, event duration in comparison with the two other catchments where extended green areas dwarf these effects, reported also by Rowny and Stewart (2012). However previous findings reported that *E. coli* and int. enterococci variation was found to be similar independent from the catchment characteristics with no clear trend between different sites and events (McCarthy, 2009; Hathaway and Hunt, 2011).

3.3 TSS and indicator bacteria correlations

The linear relationship between all five studied parameters was evaluated using the Pearson correlation coefficient at 95% confidence interval. At the green recreational site a strong positive relationship between TSS and total coliforms was detected, thus total coliforms which are known to be of both natural and faecal origin seem to follow TSS patterns in more developed catchments suggesting other available bacteria sources than natural input (soil, wildlife) from green catchments. *E. coli* was moderately correlated to TSS, total coliforms and int. enterococci, respectively. No significant linear relationships were found in the residential catchment. In the large central catchment significant relationships were observed between *E. coli* and total coliforms whereas results from the small central site indicated a nearly perfect linear relationship between total coliforms and int. enterococci.

In previous studies a strong relationship was reported between TSS and indicator bacteria (Olyphant et al., 2003; Jeng et al., 2005). In contrast, in this study the only significant correlation between these two parameters was found at the green site indicating common sources at this site. Since no significant relationship could be found at the three other sites, further investigation of bacteria relationship with particle size distribution and solids-water phase is recommended. No significant relationships were found in the residential catchment, thus the investigated parameters have no statistical relationship between them. The strong relationships found in the central catchments indicate that total coliforms are strongly correlated with *E. coli* or with int. enterococci suggesting the variety of sources influenced by catchment size, land use and complexity.

Table 4. Pearson correlation with p-values (in italics) between TSS, total coliforms (TC), *E. coli* (EC), int. enterococci (IE) and *C. perfringens* (CP) showing strong relationships (bolded font) at 95% C.I.

	Green recreational				**Residential**				**Central large**				**Central small**			
	TSS	TC	EC	IE	TSS	TC	EC	IE	TSS	TC	EC	IE	TSS	TC	EC	IE
TC	**0,85**				0,34				0,35				0,19			
	0,00				*0,07*				*0,17*				*0,39*			
EC	**0,61**	**0,46**			0,32	0,34			0,40	**0,70**			0,24	-0,02		
	0,00	***0,02***			*0,09*	*0,07*			*0,11*	***0,00***			*0,28*	*0,92*		
IE	0,07	-0,17	**0,44**		0,35	**0,49**	**0,47**		0,16	0,45	**0,60**		0,16	**0,97**	-0,10	
	0,72	*0,41*	***0,02***		*0,06*	***0,01***	***0,01***		*0,54*	*0,07*	***0,01***		*0,46*	***0,00***	*0,66*	
CP	0,04	-0,22	0,29	0,37	0,17	0,14	**0,57**	0,32	0,38	0,06	-0,25	0,04	0,40	-0,15	0,00	-0,11
	0,84	*0,28*	*0,14*	*0,06*	*0,37*	*0,45*	***0,00***	*0,09*	*0,14*	*0,83*	*0,34*	*0,87*	*0,06*	*0,50*	*0,99*	*0,63*

Although the presented findings show significant differences between study sites, the data is too limited for further generalization due to difficulties related to manual sampling procedure during entire storm events. In total 12 sets of data have been collected, 3 events in each catchment with low or moderate storm intensity and 6 mm maximum total rainfall. Further sampling will be conducted to assess the impact of larger storm events on stormwater quality variation and site specific sources. Further research is needed in detailed source characterization with a more robust dataset including larger rain events and seasonal variation.

4 CONCLUSIONS

Indicator bacteria and TSS concentrations varied significantly between study sites and within the storm runoff events. During storm runoff, total coliform and int. enterococci concentrations increased 10^2 to 10^3 times, compared to those in baseflow. Compared to these two parameters, considerably lower concentrations were observed for *E. coli* and C. perfringens. Bacteria concentrations differed significantly among the sampling sites and partly, a first flush phenomenon was observed. Similar intra-event variation trends were observed for total coliforms and TSS between sampled events in the two catchments with no baseflow. Other constituents were more affected by precipitation and flow characteristics, with no clear trend between storm events. In the less developed green catchment moderate to strong positive relationships were observed between TSS, total coliforms, *E. coli* and int. enterococci, suggesting similar sources for these constituents. In contrast no significant linear relationships were found in the residential catchment. In the large central catchment *E. coli* and total coliforms were strongly related whereas results from the small central site indicated a nearly perfect linear relationship between total coliforms and int. enterococci. In compliance with the European and Swedish bathing water, raw water and drinking water regulations, stormwater runoff is a threat for receiving waters designated for raw water extraction and recreational purposes. Site specific variations and relationships are related to catchment related sources, catchment and system characteristics. Indicator bacteria, more specifically E. coli levels were not comparable to previous findings, one explanation could be that North- European climate has a different impact on the variation of more climate-sensitive indicator bacteria in stormwater runoff. In further studies local variations of different indicator bacteria strains will be evaluated in seasonal context.

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