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MICROBIOLOGICAL RUNOFF WATER QUALITY FROM A GREEN ROOF AND IN AN OPEN STORMWATER SYSTEM

Mikrobiologiska föroreningar i avrinningsvatten från ett grönt tak och i ett öppet dagvattensystem

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Abstract

Microbiological quality of stormwater runoff from a green roof and in an open stormwater system in Augustenborg, Malmö, Sweden was studied. Since the stormwater is managed in an open system there is a possibility of human contact with that water and a potential risk for public health. Four locations have been selected as sampling points: a green roof, a ditch, and two ponds. *E. coli*, total coliforms, Pre. *Clostridium perfringens*, and intestinal *Enterococci* are used as microbiological indicators to evaluate the potential stormwater contamination of fecal origin. Grab stormwater samples have been collected after rain events during 6 May, 24 October, and 26 November 2009. Comparison of obtained results is done between sampling sites, between sampled precipitation events, and between different indicators. The obtained results are also compared with bathing water standard for EU countries and guidelines for surface water quality by the Swedish Water & Wastewater Association. The highest concentration of microbiological indicators was found in water samples taken from the ditch. The least polluted stormwater samples were collected in the pond 1. The green roof runoff was contaminated by total coliforms and intestinal *Enterococci*. Most of the collected samples did not meet the standards for bathing water quality, except for the pond 1. In general, the stormwater in Augustenborg open system can be judged as polluted water from a microbiological point of view. There is a need for further research for better linkage between microbiological contamination in stormwater, rainfall intensity, and a season.

Key words – microbiological indicators, stormwater quality, open stormwater system, green roof

Sammanfattning

Studien undersökte mikrobiologisk kvalité hos avrinningsvatten från ett grönt tak och i ett öppet dagvattensystem i Augustenborg, Malmö. Eftersom dagvattnet hanteras i ett öppet system finns det möjlighet för mänsklig kontakt med vatten och en risk för folkhälsan kan uppstå. Fyra platser har valts ut som provtagningspunkter: ett grönt tak, ett dike och två dammar. Dagvatten prover togs efter nederbörds tillfällen; 6 maj, 24 oktober och 26 november 2009. I dessa prover analyserades halterna av totala koliformer, *E. coli*, Pre. *Clostridium perfringens* och intestinala Enterokocker. Resultaten för de olika provtagningspunkterna jämfördes med badvatten standard för EU-länderna samt riktlinjer för ytvattenkvalitet från Svenskt Vatten. Den högsta koncentrationen av mikrobiologiska indikatorer återfanns i vattenprover tagna från diket. De minst förorenade dagvattenprover togs i dammen 1. Avrinning från gröna tak var förorenad med totala koliformer och intestinala Enterokocker. De flesta dagvattenprover uppfyllde inte normerna för badvattenkvaliteten och för ytvattenkvalité, förutom prover som var tagna i damm 1. Generellt kan dagvatten i Augustenborg öppet system bedömas som förorenat från en mikrobiologisk synpunkt. Det finns ett behov av ytterligare forskning för bättre koppling mellan mikrobiologiska föroreningar i dagvatten och nederbörds intensitet samt säsong.

Introduction

Numerous previous studies show that stormwater runoff is polluted with different indicator bacteria and contributes with microbiological pollution to surface waters. The degree of pollution depends among others on the site character and land use, climate, and preceding weather conditions. Previous studies show that the poorest quality stormwater can be associated with street markets and poorly maintained residential locations (Ellis 1993). Mandatory levels for water quality in recipients of stormwater are often shown to be violated, particularly following severe storm events (Jacobs and Ellis 1991). Nascimento et al. (1999) reported that gastroenteritis, skin, and respiratory diseases occurred after a contact with infected stormwater in urban detention ponds. Mallin et al. (2009) investigated the impact of stormwater runoff on water quality of an urban, a suburban, and a rural stream. They found that excessive coliform abundance frequently occurred in the most urbanized catchments and that they were significantly higher during the rain events than during dry periods. Fecal coliform bacteria in water receiving storm runoff were positively correlated with total rainfall preceding sampling.

A literature review shows that most of the knowledge regarding microbiological pollution of stormwater comes from studies of stormwater receiving bodies. Fewer investigations are available from monitoring of water quality in stormwater sewers and outflows. Studies of microbiologal quality in open stormwater systems located in urban areas are rare; studies of microbiological quality of green roof runoff are not being published. The risks of microbiological pollution of stormwater in open stormwater channels and ponds in the light of existing knowledge can be considered as high: particularly if residential areas are not well maintained, if there are ongoing commercial activities in form of street markets, if animals are abundant in an area, and in particular after intense precipitation events. Also Characklis et al. (2005) showed that wet conditions result in by far more contaminated stormwater receiving surface waters comparing with dry conditions. The risk during colder seasons may be lower (Young and Thackston 1999, Hathaway et al. 2010). Kurz (1998) showed that little information was available about effectiveness of the current stormwater treatment systems in the removal of microbiological pathogens. He estimated that the fecal pollution is two to five times more in stormwater than in secondarily treated wastewater.

In Sweden, there is an ongoing work to create guideline values for stormwater quality discharged from urban areas to recipients (Riktvärdesgruppen 2009). In these guidelines the microbiological parameters are not yet included. Åström and Petersson (2009) indicate that one of the major research gaps regarding microbiological pollution of reservoirs used as drinking water sources lies in the poorly investigated contribution of microbiological pollution from stormwater. There is also an increasing focus on onsite stormwater management, often in open ponds and channels making use of stormwater in landscaping, making it visible and at the same time increasing the possibility of human contact with stormwater runoff. Therefore, especially regarding open stormwater management systems in urban areas, health risks linked to contact with stormwater in those open systems need to be investigated.

This paper is a summary of a Master thesis presented at the Department of Water Resources Engineering, Lund University, Sweden (Hussain 2010). The study is a pilot investigation aiming to assess microbiological pollution in an open stormwater system in a residential area of Augustenborg, Malmö, Sweden. Water samples are taken three times during autumn 2009; each time at four different sampling sites. The sampling sites are: a green roof, an open channel, and two different wet ponds. The following microbiological indicators are investigated: total coliform bacteria 35 °C, *Escherichia coli* (*E. coli*) 44 °C, Pres. *Clostridium perfringens*, and intestinal *Enterococci*. These indicators are commonly used to monitor microbiological quality of water in reservoirs. The objective of monitoring is to identify fecal pollution. Total coliforms, however, may be present naturally in soil and are alone not enough indicatory of fecal pollution. The other three indicators are of fecal origin. Intestinal *Enterococci* is an indicator organism that does not increase in the environment and also survives longer in comparison with *E. coli* (WHO 2008). *Clostridium perfringens* can be used to indicate fecal pollution which took place longer time ago, however it can be difficult to identify its source (WHO 2008). The choice of studied indicator organisms is made to support assessment of fecal pollution and related risks.

Study site

Augustenborg is a residential area in Malmö, Sweden. Malmö is the third largest city in Sweden in term of population. The climate is temperate and average annual precipitation is about 600 mm. An open stormwater system is used in Augustenborg since the late 1990s (Villarreal et al. 2004). In the open system, the stormwater is kept on the surface in the city environment. Stormwater runoff from green roofs, hard roofs and other impermeable surfaces in the residential area is collected through gutters into system of channels and ponds. Residents and visitors in the area can easily come in contact with that water.

Fig. 1. *Green roof – sampling point 1.*

Fig. 2. *Ditch – sampling point 2.*

The open stormwater system in Augustenborg including green roofs has been previously studied and the system is described in, among others: Villarreal et al. (2004) (open stormwater system), Bengtsson et al. (2004) (hydrological functions of green roofs), and Czemiel Berndtsson et al. (2006) (runoff water quality from green roofs). The microbiological quality of green roofs runoff water has not previously been studied.

Methodology

In order to evaluate the microbiological quality of stormwater in Augustenborg open system and to assess health risk for public in the area an investigation of microbiological water quality has been carried out. Four microbiological indicators have been chosen to serve as a tracer for fecal contamination: *E. coli*, total coliforms, *Clostridium perfringens*, and intestinal *Enterococci*. All these parameters have been measured in grab stormwater runoff samples. The samples have been collected on three different occasions; 6 May, 26 October and 24 November 2009. The water samples were taken at the following four locations from the Augustenborg stormwater systems: green roof (Fig. 1), a ditch (Fig. 2), pond 1 (Fig. 3), and pond 2 (Fig. 4); one sample at each location and event. The green roof (sampling site 1) is not acces-

Fig. 3. *Pond 1 – sampling point 3.*

Fig. 4. *Pond 2 –sampling point 4.*

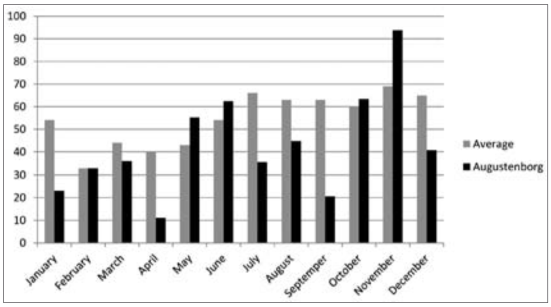

Fig. 5. *Monthly precipitation in (mm) in Augustenborg during the study year 2009 and the average monthly precipitation in the region between years 1960–1990 (SCB 2010).*

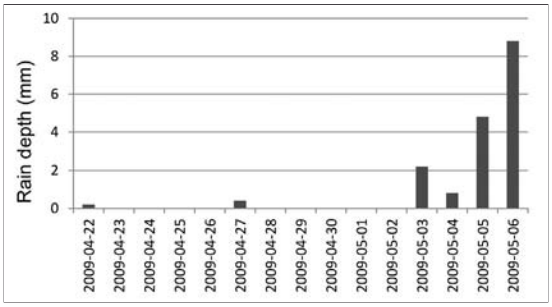

Fig. 6. *Daily rainfall depth (mm) in Augustenborg from 22 April 2009 to 6 May 2009 prior to the first sampling day (06-05-2009).*

sible for visitors. It was not watered or fertilized during the study year. The roof receives nutrients through rain water during precipitation events. It is being observed that the roof is inhabited by birds and that seagulls breed on it. The birds' feces may be a potential source of fecal contamination of runoff. The green roof section from which runoff is collected is 1.25 m wide and 4 m long. Details on green roof material and construction can be found in Czemiel Berndtsson et al. (2006). A ditch (sampling site 2) is situated in the upstream part of the open stormwater system. It is dry in periods with no precipitation; it receives runoff after precipitation events from hard roofs, green roofs and paved areas in the upstream area. Potential sources of fecal contamination of stormwater are dogs' feces and birds' feces. Pond 1 (sampling site 3) is a part of a system of two ponds and a wet channel between which the water is circulated continuously using a pump. Additional aeration of circulated water takes place in a fountain arrangement that is constructed in the other one of two ponds. During longer periods with no precipitation ponds receive additional water from mains supply. There are no records available on when and how much water is added to this system. Pond 2 (sampling site 4) is the most downstream situated element of the open stormwater system in Augustenborg. It receives runoff from the entire upstream area: roofs, yards in residential area, streets, and school yards.

Runoff from the green roof was collected in a plastic barrel of capacity 25 l that was connected by a plastic hose to a green roof section (see Fig. 1). The barrel has been emptied and cleaned with tap water after each collection event. One grab water sample was taken from the barrel after each of the sampled precipitation events. At the other three sites (two ponds and ditch), the water samples were collected manually in plastic bottles by submerging the bottles under the water surface until the sampling bottle filled up. Sampling bottles (300 ml) were sterile and they were prepared at the laboratory according to the requirements for sampling equipment for collecting water for microbiological analysis. The samples have been taken after rain events which generated enough runoff for the system to allow water sampling. The water samples were delivered to the laboratory immediately after collection. Analyses were performed by VASyd Vattenlaboratoriet (Box 191, 201 21 Malmö, Sweden). Concentration of *E. coli*, total coliforms, and intestinal *Enterococci* have been measured by number of each individual parameter per 100 ml water sample (number/100 ml) while the Pres. *Clostridium perfringens* was measured by a colony forming unit (CFU) in a 100 ml water sample.

Precipitation records for the study period and the study site (Augustenborg) were obtained from VA-Syd. The daily precipitation data during a week preceding each sampling is reported in this paper and used in discussion of results.

Results and discussion

The monthly precipitation at the study site Augustenborg during the study year 2009 is compared with the average monthly precipitation in the region during years 1960–1990 (SCB 2010) (Fig. 5). The comparison shows that the monthly precipitation in November exceeded by more than 20 mm the normal precipitation of that month. Precipitation recorded in May 2009 was also higher than normal while precipitation recorded in October was close to normal. The weather conditions may influence the bacterial load in stormwater runoff, generally the more runoff the more dirt can be washed off from hard surfaces.

In Figs. 6–8 the daily precipitation in Augustenborg Malmö during the sampling day and a number of preceding days is presented. On the first sampling occasion (2009-05-06) the samples were taken after an intense precipitation event (total 8.8 mm) occurring on that

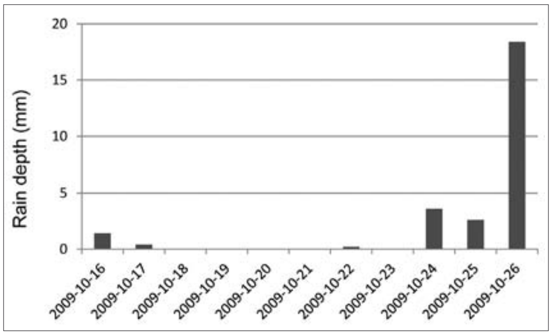

Fig. 7. *Daily rainfall depth (mm) in Augustenborg from 16 October 2009 to 26 October 2009 prior to the second sampling day (26-10-2009).*

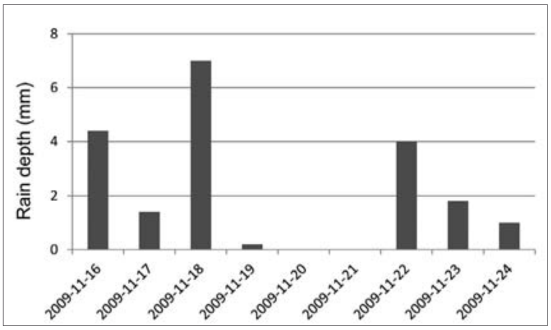

Fig. 8. *Daily rainfall depth (mm) in Augustenborg from 16 November 2009 to 24 November 2009 prior to the third sampling day (24-10-2009).*

day. On the second sampling occasion (2009-10-26) samples were taken at noon, after 1.6 mm precipitation on that day. On the third sampling occasion (2009-11-24) samples were taken at 8 o'clock in the morning; the precipitation on that day prior to sampling was 0.4 mm. Notice that precipitation amount during two days preceding sampling were very similar on the second and third sampling occasions; they were equal about 4 and 2 mm respectively, in both cases. The stormwater system was in wet condition during all sampling ocassions.

The results of water quality analyses are presented in Figs. 9–12.

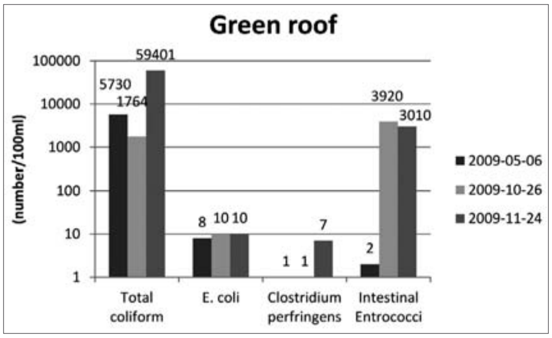

Fig. 9. *Microbiological indicators (in number/100 ml, Pres.* Clostridium perfringens *in CFU/100ml) in stormwater runoff samples from the green roof.*

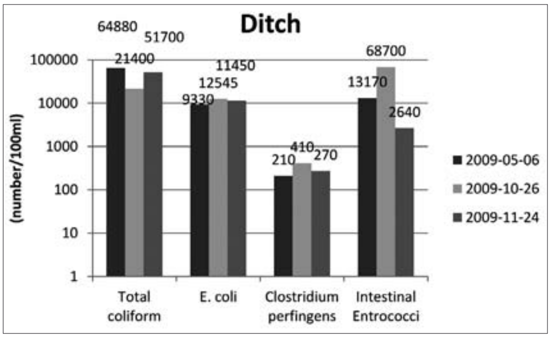

Fig. 10. *Microbiological indicators (in number/100 ml, Pres.* Clostridium perfringens *in CFU/100ml) in stormwater runoff samples collected from the open ditch.*

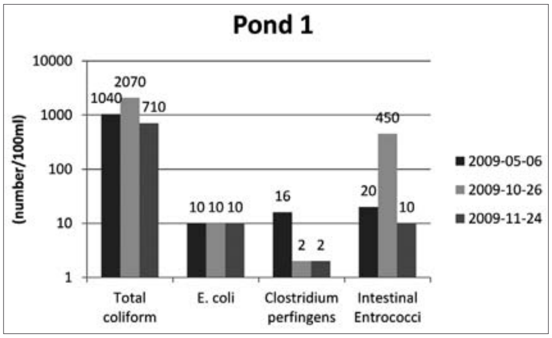

Fig. 11. *Microbiological indicators (in number/100 ml, Pres.* Clostridium perfringens *in CFU/100ml) in stormwater samples collected from the pond 1.*

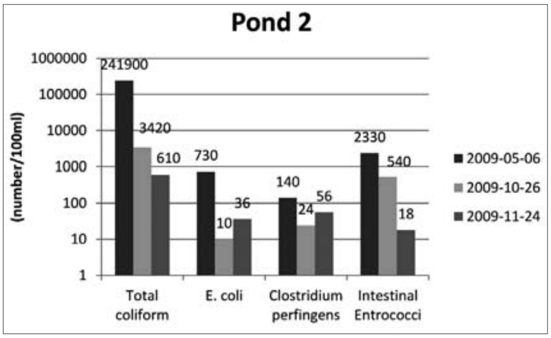

Fig. 12. *Microbiological indicators (in number/100 ml, Pres.* Clostridium perfringens *in CFU/100ml) in stormwater samples collected from the pond 2.*

Table 1. *Microbiological criteria for bathing water quality (EC 2006).*

Parameter	Excellent quality*	Good quality*
Intestinal *Enterococci* (cfu/100 ml)	200	400
Escherichia coli (cfu/100 ml)	500	1000

* Based on 95 percentile evaluation

When comparing the stormwater quality between the four sampling sites it is generally seen that the most polluted runoff is found at the ditch while the least polluted stormwater is found in the pond 1 followed by the runoff from the green roof. The open ditch situated in the residential area remains dry in periods between rains. It may collect dirt and garbage and cause higher pollution of first portion of runoff: dilution effect may be less in dry elements of open stormwater system than in wet ones. On the other hand, the pond 1 is designed and maintained to be wet in all kinds' of weather (in dry periods the pond is filled with water from mains supply). The stormwater in the pond 1 is circulated in a system of two ponds and a channel and aerated in a water fountain. This management is possibly contributing to water treatment and in effect lowest level of microbiological indicators.

Recall that the first sampling took place directly after an intense precipitation event of 8.8 mm and two other samplings were done after smaller rain events occurring during two days preceding sampling (in total about 6 mm). For the sampling points the ditch and the pond 1, the data show no relation between the bacterial indicators and the type of preceding precipitation. For the pond 2, which is situated downstream in the system, it is seen that the pollution load regarding all indicator bacteria is highest after the largest precipitation event during the first sampling occasion. This is similar to results of other studies (Jacobs and Ellis 1991, Characklis et al. 2005, Malin et al. 2009), showing that there is a general relation between the size of a precipitation event and the bacterial contamination of stormwater; a larger storms tend to create a more polluted runoff. At the green roof sampling station an unexpected result is obtained for the parameter intestinal *Enterococci*; the more intense rain during the first sampling occasion resulted in intestinal *Enterococci* being almost non present in runoff while the less intense precipitation events on preceding days for the second and third sampling occasions result in similar concentrations of intestinal *Enterococci* in roof runoff water. From this result it is seen that the larger rain creates cleaner runoff. However, there may be other explanations of this result, for example different sampling seasons or accidental pollution occurring prior to sampling (e.g. birds feces deposited on the roof). To be able to confirm and explain such results, more studies are needed.

The results show that – applied to stormwater – total coliforms are found in highest numbers among all four studied microbiological indicators at all study sites. As total coliforms may be present naturally in soil they cannot be used alone as indicator of fecal pollution of stormwater. The concentrations of *E. coli* in green roof runoff, pond 1 and pond 2 (the last one with exception to the first studied event) are low. However, parameter intestinal *Enteroccocci* – an indicator organism that does not increase in the environment and survives longer than *E. coli* – indicates that stormwater is polluted with fecal matter. Regarding stormwater collected in the ditch, all parameters indicate fecal pollution. Regarding parameter *Clostridium perfringens* it is the ditch and pond 2 that show highest contamination. Some studies link the abundance of *Clostridium perfringens* in stormwater with the presence of dogs' feces. Dog feces contain an abundance of thermo tolerant spores of *Clostridium perfringens* (Leeming et el. 1989).

To assess the potential risk for human health after a contact with stormwater we use the criteria for bathing water quality (EC 2006) (Table 1). Elements of an open stormwater system are not used as recreational water; however, especially in warmer seasons, they may attract for example children to enter the water reservoir for playing and bathing. The ponds and the channels are shallow and are situated in residential area close to playgrounds for children. The results of the study show that, regarding parameter *E. coli*, stormwater at the sites pond 1 and the green roof fulfill the criteria for excellent quality bathing water. Stormwater at the site pond 2 fulfills criteria for good quality bathing water when *E. coli* is concerned. Regarding stormwater runoff in the ditch the criterion of *E. coli* content for good water quality is at all three sampling occasions exceeded by about 10 times. Regarding the parameter intestinal *Enterococci* it is shown that the stormwater at all studied sites contains contaminants of fecal origin and does not fulfill the requirement for good bathing water quality. Overall, in the light of requirements in bathing water directive (EC 2006) for good water quality it is seen that the stormwater in the pond 1 nearly fulfils requirement of good bathing water quality thus risks for human health after contact with that water can be evaluated as low. Stormwater in the open ditch and in the pond 2 is polluted with microbiological indicators and may pose risk to human health after contact with the water. More studies in different seasons are needed to further investigate parameters influencing microbiological stormwater quality in an open stormwater system.

In Sweden, stormwater managed in separate stormwater systems, both open and combined, can be discharged to water recipients without any treatment. Commonly, there is no treatment applied to stormwater runoff before it reaches water reservoirs. At the same time numerous surface water reservoirs are used as sources of drinking water. In Sweden, half the amount of the drinking water produced comes from surface water. The microbiological surface water quality and the quality of stormwater which is discharged to surface reservoirs are thus relevant for production of drinking water. The Swedish Water & Wastewater Association published guidelines for surface water quality (SvenskVatten, 2008). These guidelines include, among others, the following recommended limits for microbiological indicators: total coliforms should be lower than 5000 cfu/100 ml, and both *E. coli* and intestinal *Enterococci* lower than 500 cfu/100 ml. In the light of this guideline the stormwater, as investigated in this study in the pond 1, fulfills the raw water requirement, while stormwater at other three sites does not.

Conclusion

The highest concentration of microbiological indicators was found in water samples taken from the ditch which is dry in between rains and receives runoff after precipitation events. The least polluted stormwater samples were collected in the pond 1 – a pond maintained as wet, aerated and receiving water from both stormwater and mains supply. The green roof runoff was contaminated by total coliforms and also intestinal *Enterococci*. Most of the collected samples did not meet the standards for bathing water quality, except from the pond 1. In general, the stormwater in Augustenborg open system can be judged as polluted water from microbiological point of view. Contact with stormwater in open system may expose humans at health risks. Microbiological contamination of fecal origin in the open stormwater system is higher than recommended water quality at surface water being source of drinking water. Stormwater reservoirs are not used as drinking water reservoirs; however, stormwater is often discharged to surface water thus may contribute to water contamination. There may exist a considerable risk of surface water pollution from stormwater discharges. There is a need for further research for better linkage between weather (e.g. season, temperature, precipitation), land use, type of stormwater management (e.g. dry or wet facility, aeration or not, water circulation or not, channel or pond) and microbiological contamination in stormwater.

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