URBAN STORMWATER QUALITY AND QUANTITY IN THE CITY OF TALLINN

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Abstract:

This study aimed to provide an overview of stormwater quality and quantity, the impact on waterbodies and the likelihood of its usage in stormwater management. The potential impacts were assessed using statistical analysis following HELCOM, EU Directive and Estonian requirements. Further, Seasonal behaviour, variability, tentative sample size and frequency were examined using strongly dependent parameters obtained from correlation studies. Results show that the average concentrations of pollutants are not extremely high except microbiological parameters. Most basins have positive correlation of 0.4 - 0.6 between flow and suspended solids (SS), as well as of 0.4 - 0.95 between total phosphorus (TP) and SS. As for seasonal variation, large amount of SS is transported in spring whereas in summer, runoff and SS are consistent against winter and autumn. However, at a 70% confidence interval, there is considerable uncertainty in the mean flow and concentrations. Flow and SS have higher uncertainty than conductivity, BOD7, total nitrogen (TN) and TP. It was discovered that most of the samples belong to a small range of daily rainfall (<5 mm) and there is no measurement for first flush. Variability and inadequate representation of rainfall range calls for comprehensive sampling and validation of the data intended to use in stormwater management programs.

Key Words: Urban stormwater, pollution load, monitoring program, seasonal variation

Introduction

Urbanisation with its uncontrolled impervious surfaces increases stormwater runoff and transports pollutants to the receiving waterbodies. These pollutants not only have an adverse effect on human health but also to indigenous plants and animals (Jacobson, 2011; Christensen et al., 2006; Leecaster et al., 2002). Sediment from stormwater runoff is a potential problem source (Lau & Stenstrom, 2005; German & Svensson, 2002). In order to prevent and minimise stormwater runoff volumes and the pollution load, the Baltic Sea member states jointly pooled their efforts through the Helsinki Commission towards the ecological restoration of the Baltic Sea (HELCOM, 2002). Furthermore, the EU Water Framework Directive (WFD) as well as the Estonian Water Act (EWA) (RTI, 2011) have set a target to protect all waters against pollution and to achieve the good status of all waters by promoting sustainable water and wastewater management (EC, 2000).

The eutrophication of inland waters and the sea is one of the major environmental problems in the Baltic Sea Region, including Estonia (Kotta et al., 2009; Iital et al., 2010; Elofsson, 2010). The urban runoff load has made a substantial contribution towards raising nutrient levels in waterbodies (Taylor et al., 2005; King et al., 2007). HELCOM has adopted an action plan to considerably reduce the anthropogenic nutrient load by 2021 (HELCOM, 2007).

The revised Environmental Charges Act (RTI, 2005) did not elicit the expected reduction in pollutant discharge into waterbodies because the stormwater pollution load is not easily measurable. The stormwater load measurement expenses are significantly higher than the collected tax returns. The specialists in the Ministry of the Environment had not yet defined exactly what kind of mean concentration should be measured (Lääne & Reisner, 2011). There is real need to study urban stormwater pollution in order to develop methods for the reduction of stormwater pollution exports to the sea (Hood et al., 2007), including both flood control and pollution control.

To address these problems and to select appropriate water protection measures, the first objective that needs to be set is to activate the assessment of the status of water, including a comprehensive interpretation of the monitoring data that form the basis for the planning and implementation of protection measures. In addition, low variable and representative data are standard requirements for stormwater management approaches, as they are susceptible to the actual total pollution load and the mean concentration of pollutants. This study will provide a status update on stormwater quality and quantity in the city of Tallinn through analysis of the monitoring data. The main objectives of the study are to assess stormwater quality and quantity; the spatial and seasonal variation of stormwater discharges and pollution load; and to identify, the likelihood of data to be meaningful, representative and verifiable quality on the basis of existing routine monitoring programme, so that they can effectively aid in managing stormwater runoff.

Material and Method

Site Description

Tallinn, the capital of Estonia, is situated on the southern coast of the Gulf of Finland, in north-western Estonia. It has total area of 156 sq km with a population of 417,741, and population density of 2,614 per sq km. The average precipitation in Estonia is 550–750 mm and the mean runoff 280–290 mm per year. The climate in Tallinn is fairly cold in winter with an average temperature of 1.93 °C and a maximum low of -32 °C, a cool spring with little precipitation, a moderately warm summer with an average temperature of 8.64 °C and a high of 32.3 °C, and a rainy autumn.

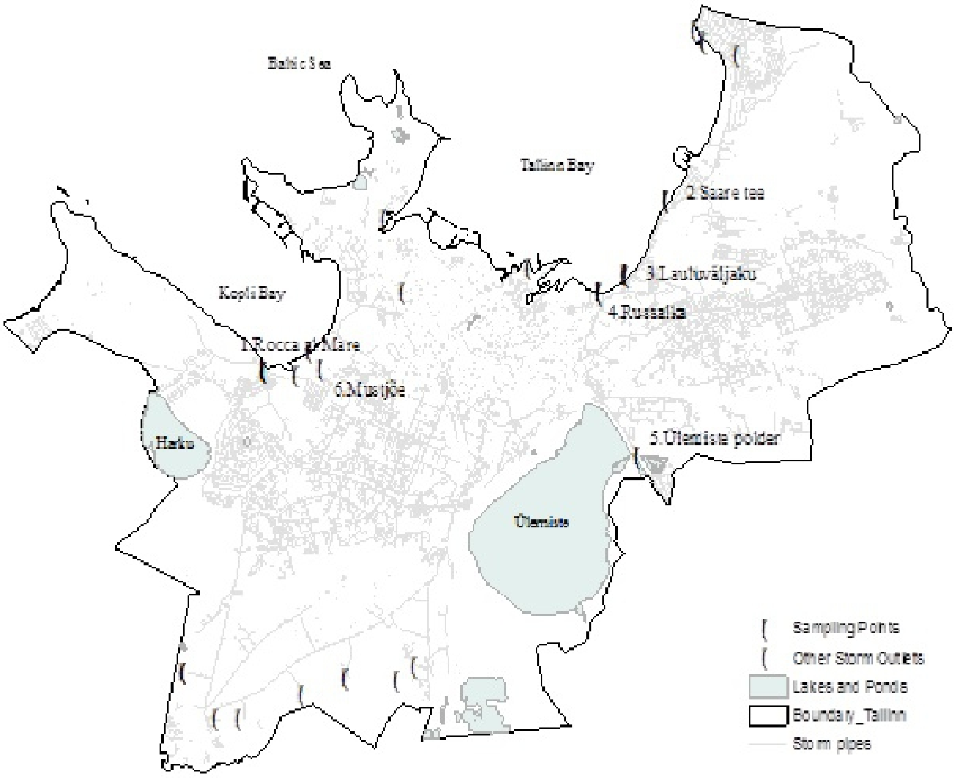

Figure 1: Sampling sites and their location in Tallinn

The area of the stormwater system of Tallinn is about 6,500 hectares and the length of stormwater conduits was 414 km in 2011 (Tallinna Vesi, 2012). Stormwater from residential and industrial areas is either diverted to municipal Waste Water Treatment Plants (WWTPs) and treated with sewage or is collected in a separate stormwater system and mainly disposed to waterbodies without any treatment. The city centre has a combined sewerage system while the other parts have mostly separate systems. There are 23 stormwater outlets that mostly discharge water to the coastal sea (*Figure 1*) in the Tallinn catchment area. Six major storm outlets: Rocca al Mare, Saare Tee, Lauluväljak, Russalka, Ülemiste and Mustoja are included in the monitoring program organised by the Tallinn City Environment Department. For this study, these six outlets are examined, between them covering a catchment area of almost 4,000 ha, as they are supposed to form a separate stormwater system in Tallinn city. Among them, the Mustoja outlet is the largest and serves almost 30% of the total area. The second biggest is Lauluväljak and the smallest is Saare tee (*Table 1*).

Table 1: Area of Drainage basins and their characteristics

No.	Basin	Area, ha	% Coverage	Receiving water body	Characteristics
1	Rocca al Mare	816	21.5	Kopli Bay	mostly storm and surplus water from the apartment house areas, from pools in the zoo during water exchange, an increase in impervious areas is noticed in the catchment.
2	Saare tee	156	4.1	Tallinn Bay	storm and drainage waters from private house area, collected via open ditches and Varsaallika spring (basin 1.6 km^2), sewage discharges from the private house area can occur
3	Lauluväljak	961	25.3	Tallinn Bay	mostly high density area with impervious area one third of total area. Runoff collected from residential and industrial, sewage discharges can occur from this area
4	Russalka	734	19.3	Tallinn Bay	mostly consists of the Ülemiste polder storm and drainage waters and Lake Ülemiste surplus water after heavy and continuous rains, and during the meltwater period
5	Ülemiste polder			Tallinn Bay	storm and drainage waters from the industrial district and private house areas, airport treated stormwater and runway stormwaters, Ülemiste polder drainage water
6	Mustoja Paldiski Road	1,128	29.7	Kopli Bay	mostly storm and drainage waters from private house areas, apartment houses and industrial district collected via ditches, open channels and pipes into the Mustoja River, increase in impervious areas is noticed in the catchment, sewage discharges from one of the private house areas can occur
	Total	**3,795**			

Data source, sampling procedure and chemical analysis

Stormwater monitoring has been carried out since the late 1980s, but it only became regular in the 1990s. For this study, stormwater monitoring data for the years 2005 and 2008-2011 have been obtained from monitoring reports (Pauklin et al., 2005-2011). In this monitoring system, grab samples were collected 4–6 times a year from the stormwater outlets (see *Figure 1*). The data was measured only once in 2010. The sampling procedure adhered to the sampling requirements in Council Regulation no. 30, 5 May 2002, of the Estonian Ministry of Environment. For 2012, samples were measured by both Tallinn University of Technology and AS Tallinna Vesi. Other samples were taken by the Estonian Environmental Research Centre, all of which are competent bodies according to EN ISO/IEC 17025:2005 for conducting tests in the field of water analysis (accreditation scope on the Estonian Accreditation Centre). Data for 24 hour precipitation from the Tallinn-Harku Meteorological Station located approximately 20 km from the study area was obtained from the Estonian Meteorological and Hydrological Institute (EMHI) for 2005–2012. Samples were tested for parameters such as conductivity, pH, temperature, suspended solids (SS), total nitrogen (TN), total phosphorus (TP), biological oxygen demand (BOD_7), hydrocarbons (HC), Escherichia Coli and Enterococci using analytical methods based on ISO 10523, ISO 5667-10, EVS-EN 25814, EVS-EN 27888, EVS-EN 872, ISO 5815-1, SFS 5505, EVS 9377-2, EVS 9308-1, EVS-EN ISO 7899-2 and EVS-ISO 6340, respectively.

Data Analysis

Normal statistical analysis was carried out to estimate arithmetic means, median, quartiles, correlation coefficient, coefficient of variance (CV) and confidence intervals (CI). The relationship between parameters were analysed through correlation coefficient to obtain prior parameters according to which seasonal variation were observed. Further, with CV and CIs, it was attempted to assess variability of data. Finally, variability and representativeness of data to rainfall intensity were scrutinized through sample size and frequency.

The grab samples for a year did not amount to more than six, except for Mustoja (consists 12 in 2005). It was known from rainfall data of the available data source period that the main parameter of hydrology (average annual rainfall) did not vary significantly .The highest deviation from the mean was 18% only in 2005. Thus, these samples from six years for each basin were combined to attain a higher number of samples, assuming that there was no excessive change in the urban environment.

In terms of the estimation of average total mass emission, it is viable to measure grab sampling with continuous flow measurements over a specific time period (day, week, month), instead of instantaneous flow measurement (Fogle et al., 2003; HELCOM, 2006). For instantaneous flow and concentration measurement, the load calculation was carried out by multiplying the average load by 365 days. Therefore, the mean flow and load over six years in each basin were deemed the average annual flows and loads that are discharged into the waterbodies.

To analyse seasonal variation, the twelve months were categorised with regard to the hydrological year as spring (February, March and April), summer (May, June and July), autumn (August, September and October) and winter (November, December and January). In this way, the data were separated according to the sampling date and grouped into 4 seasons irrespective of yearly variation.

Sampling time during a storm event affects runoff. With correct sampling frequency, it avoids the bias of the first flush and better characterises the mass emission of the event (Lee et al., 2007). To evaluate the sampling programme in terms of sampling number and frequency, it was assumed that there was a constant area of impervious surfaces throughout the study period so that flow can be mainly related to rainfall intensity, though the correlation between daily rainfall intensity (DRI) and runoff was 0.64. Snow cover period was separated and excluded from the analysis because snow melt affects hydrology in a different way. The rainfall data was stratified into three sizes according to rainfall range (small: <5 mm, medium: 5–20 mm, and large: >20 mm). The number of samples that can address rainfall range is hard to determine in regard to grab samples because a grab sample is taken at a particular flow and time, and finding the rainfall intensity that generates that particular flow is almost impossible. Therefore, approximate DRI according to minimum and maximum flow was sought from 24 hour precipitation data. Then the rainfall for other discharges was interpolated to put into the range, and the amount of rainfall within that range was calculated. This rainfall number is actually the number of samples within that particular range. After comparing with the required number of samples, the percentage deficit and surplus was calculated.

Result and Discussion

Stormwater general statistics

The flow and pollution parameters from sampling for six years at six stormwater outlets are summarised in *Table 2*. The total number of samples for most of the parameters is 156. However, some have a lesser number than that to calculate mean flow and mean concentration. HELCOM and Regulation No 269 of the Government of Estonia, 31 July 2001, on the procedure for discharging wastewater into waterbodies or soil, provided limiting values for SS as 40 mg/l and HC as 5 mg/l in stormwater runoff (RTI, 2001). The European Union, as well as Estonia, has restricted microbiological parameters exceeding 1000 cfu/100ml Escherichia Coli and 400 cfu/100ml Enterococci for good bathing water quality (EU, 2006; RTI, 2008). There are three public beaches on the Tallinn coastline that are not far from the stormwater outlets. The ecological status of the Tallinn coastal sea was estimated as moderate (The Estonian Environment, 2012). The trophic level in the coastal sea is still quite high despite the fact that the pollution load of Tallinn WWTPs has decreased remarkably since 1990 and discharges via deep outlets do not extend to the coast; therefore, stormwater is still affecting the coastal sea.

It is noticeable that there is large variation in flow, conductivity, SS, TN, TP and pathogens. There is a higher consistency of pH that falls near the neutral range, implying that there is negligible impact from any kinds of industries. Even extreme pH values vary between 6 and 9, and lower or higher values that exceed the limits can be toxic to aquatic organisms. Saare Tee (sampling point 2) has the lowest but Mustoja (sampling point 6) has the largest flow. It reflects the fact that outflows at Saare Tee are from a small drainage basin and at Mustoja from a large drainage basin. It is also true the Russalka (sampling point 4) sometimes exceeds the runoff of the Mustoja basin. In such a case, the runoff is most likely due to the captured overflows of Ülemiste Lake during storm events.

The observed pollutant concentrations are not substantially high, excluding microbiological parameters. The mean concentration for SS is below the permissible level of 40 mg/l. Comparing flow with the transport of this pollutant, the results are found to be opposite in the case of Saare Tee. The discharge from Saare Tee is more concentrated than Mustoja. But in the case of Mustoja basin, there is a high variation in the measurement of SS. Higher readings are recorded occasionally; therefore, the maximum discharge is more than twice the mean value. Rocca al Mare (sampling point 1) is the most polluted basin in terms of mean SS. The basin has water exchange activities inside. This is probably the major contributing factor for such a large value. Ülemiste polder (sampling point 5) has natural stormwater treatment systems – polder areas – that treat stormwater and decrease the harmful effects on the receiving waterbodies. It is found that a few SS samples are above the limit of HELCOM and the Estonian stormwater requirement at 12.3%. The result shows that there are no significant effects from the SS discharged at the outlets of Lauluväljaku, Russalka and Ülemiste sites. However, this is hard to conclude for other sites because the maximum amount of these parameters is very high and it is essential to look at what factors affected those basins to cause such high values.

Table 2: Pollution parameters concentrations

S. Pt.		Q, l/s	Temp., ºC	Diss.O, mgO/l	pH	Conduct. µs/cm	SS, mg/l	BOD$_7$, mgO/l	Ntot, mgN/l	Ptot, mgP/l	HC, mg/l	E. coli, CFU/100ml	Enterococcid, CFU/100ml
	Limit		40								5		
1	Samples	23	24	24	24	24	24	24	24	24	16	10	10
	mean	95.8	8.6	9.7	7.5	818.3	38.2	10.6	4.1	0.4	0.2	571,900	27,340
	range	22.9 - 244.2	3.1 - 15	4.2 - 16	7.11 - 8.09	39.5 - 1,556	3 - 178	1.9 - 41	1.94 - 7.21	0.18 - 1.4	0.02 - 1.31	14,000 - 5,100,000	4,800 - 56,000
2	Samples	24	24	24	24	24	24	21	24	24	0	10	10
	mean	38.4	8.9	9.3	7.7	1,420.5	22.8	6.9	4.6	0.4	NA	174,743	16,018
	range	2 - 188.7	3.5 - 14.7	2.5 - 15	7.2 - 8.01	82.9 - 7,600	2 - 220	1.9 - 23	2.72 - 7	0.17 - 1.37	NA	3,600 - 1,200,000	500 - 100,000
3	Samples	19	24	24	24	24	23	13	24	24	0	4	4
	mean	80.5	9.4	10.2	7.8	1,008.9	8.4	8.1	5.0	0.2	NA	92,775	11,150
	range	13.8 - 432.9	6 - 13.9	6.5 - 15	7.2 - 8.36	78.7 - 2,220	2 - 56	3 - 35	3.1 - 9.87	0.08 - 0.8	NA	3,800 - 240,000	1,700 - 21,000
4	Samples	26	26	26	26	26	23	25	26	26	0	10	10
	mean	150.0	10.3	9.8	7.9	760.5	18.3	9.1	6.8	0.1	NA	50,975	6,218
	range	23.4 - 724.5	2.5 - 16.5	0.5 -16.7	7.44 - 8.18	58.5 - 4,100	2 - 80	3.3 - 45	1.81 - 18	0.02 - 0.3	NA	1,350 - 320,000	160 - 46,000
5	Samples	4	26	26	26	26	21	19	26	26	0	10	10
	mean	115.9	5.8	7.4	7.4	596.0	6.2	7.9	7.5	0.1	NA	432	89
	range	37.1 - 334	0.5 - 19.5	0.2 - 18	7.09 - 7.82	55.5 - 1,015	2 - 17	2.3 - 37	1.07 - 45	0.02 - 0.41	NA	0 - 1,200	0 - 350
6	Samples	32	32	31	32	32	32	30	32	32	16	4	4
	mean	184.3	9.7	9.9	7.7	558.4	32.0	5.7	4.2	0.3	0.2	29,850	3,818
	range	108 - 450.2	4.9 - 14.7	4.7 - 16	7.16 - 8.08	41 - 1,279	2 - 416	1.4 - 21	2.6 - 9.64	0.08 - 2.2	0.03 - 0.69	3,400 - 5,1000	470 - 10,000

The mean concentration of dissolved oxygen in stormwater varies typically from 7.4 to 10.2 mg/l. However, the impact on the oxygen balance is important if secondary pollutants such as oxygen demanding sediments exist. All the measured values for HC are below the permit level and it implies there are no effects due to hydrocarbons in the waterbodies.

Nutrients are a major problem for eutrophication in the Baltic Sea and urban runoff and stormwater from Tallinn city have also added a considerable amount to the sea. The mean concentration of TN and phosphorus exceed the second class – good status limit values of natural surface water in all basins. The limit values are 3 mgN/l and 0.08 mgP/l respectively. However, as shown in *Table 2*, the total N and P concentration in stormwater are substantially less than those of treated wastewater. The limit values by special water permit for Tallinn WWTP outlet are 10 mgN/l and 1 mgP/l, respectively. Microbiology varies quite a lot, with the highest values occurring in the Rocca al Mare outlet, which consists of water from the pools of the zoo. It is possible that some sanitary waste in those basins mixes with runoffs.

Total mass emission

In many studies, the average mass emission from the catchment is estimated using EMC for which composite samples or numbers of grab samples over number of storm events are required. Selecting a single grab sample from many events provides a snapshot of water characteristics for each event, but it will not tell the entire story of the whole pollutograph for any one event. The value of single grab samples is sensitive to the point in time where the grab sample is made (Davis & McCuen, 2005). There is high uncertainty in the estimation of actual mass emission from the grab samples, but it is planned to provide a general overview of mass emission to determine amount of pollutants that are discharged from the specific outlet.

Table 3: Calculated average total mass and specific mass emission for the study period (2005–2012)

Sam. Pt.	Flow		SS		BOD7		Ntot		Ptot	
	Total th. m^3/yr	Specific l/s*ha	Total t/yr	Specific kg/ha	Total t/yr	Specific kg/ha	Total t/yr	Specific kg/ha	Total t/yr	Specific kg/ha
1	3,022.3	117.45	116.2	142.37	30.6	37.47	12.2	14.98	1.2	1.49
2	1,211.6	246.28	48.4	310.07	8.4	53.53	5.4	34.55	0.7	4.22
3	2,537.8	83.74	42.7	44.46	55.5	57.76	13.5	14.07	0.6	0.67
4	4,731.8	204.42	77.8	105.93	45.7	62.27	34.5	47.05	0.4	0.58
5	3,655.8		27.2		24.9		37.7		0.3	
6	5,813.0	163.41	303.8	269.30	38.5	34.16	24.7	21.86	2.1	1.82
	20,972.3		616.0		203.6		128.1		5.3	

Table 3 shows the mass emissions for each basin in terms of the total for and specific of the catchment area. Due to the unavailability of an actual area of the Ülemiste polder, the specific weights were not calculated. It is evident that, on average, Mustoja (sampling point 6) emits the highest SS

with the largest volume of runoff. The specific load of this basin is also comparatively large. In contrast, Saare Tee (sampling point 2) is a small basin and also emits small discharges. However, it has a large specific load for SS, BOD_7, nitrogen and phosphorus. Rocca al Mare (sampling point 1) is also a significant basin for SS, BOD_7, nitrogen and phosphorus, though it emits less pollution per hectare of area than Saare Tee. The highest specific load of BOD_7 and nitrogen is released from Russalka basin (sampling point 4). Lauluväljak and Ülemiste are mild in terms of their discharging pollutant load. The average amount of mass through these six basins is 616 t/yr of SS, 203.6 t/yr of BOD_7, 128.1 t/yr of TN and 5.3 t/yr of TP through 20,972 thousand cubic metres of runoff.

As conducted by AS Tallinna Vesi, the stormwater amounts and pollution loads are not measured but are calculated using a formula based on the drainage area and annual rainfall for annual reporting to the environmental authorities. These values are smaller than in *Table 3*. The possible reasons for this could be that the meteorological station is too far and does not adequately describe the actual situation in basins and the different methodological bases.

Correlation with flow and suspended solids

It is attempted to correlate runoff pollutants with flow at every discharge point, as shown in *Figure 2*. In all the sampling sites, SS and BOD_7 have positive correlation with discharge at that particular time of sampling, while other parameters show positive correlation at certain sampling sites and negative at other sites. The Lauluväljak and Mustoja basins have a good correlation of SS at nearly 0.6. Ülemiste and Saare tee have nearly 0.4, while the remaining basins have a relation of less than 0.4.

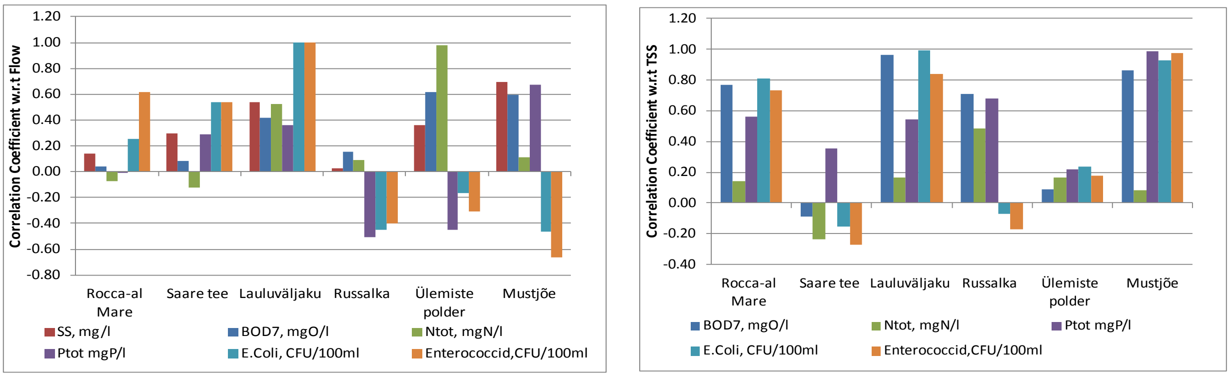

Figure 2: Correlation coefficients with respect to flow (left) and with respect to SS (right)

In relation to flow, parameters aside from SS do not have a strong one-sided correlation. As in the figure on the right, they are again correlated with SS and it is found that in three of the six sites (1, 3 and 6), parameters such as BOD_7, phosphorus and microbiological parameters have a strong positive relationship (range 0.5 - 0.95) with SS. Nutrients, especially TP, always show a positive increment with SS at correlation 0.4 - 0.95, though one site indicates a low figure at nearly 0.2. In the case of microbiological parameters, the Rocca al Mare, Lauluväljak and Mustoja basins are more sensitive to the amount of SS.

Seasonal variation

Normally, the rainy season results in a high amount of runoff from urban areas, while the dry season induces considerably low. Also, the ice melting period is very sensitive to a rise in water levels in drains and channels. During spring (see *Figure 3*), there is usually a high water depth in the conduits and channels. The spring runoff is mainly due to meltwater rather than rainfall, while the autumn and winter runoff is entirely due to precipitation. The mean runoffs at outlets are higher in the winter season than in autumn and summer. Viewing the range of runoff, it is also possible that a greater runoff can occur during autumn but the variability is high. Nevertheless, Russalka showed quite a high flow in winter. This is due to the fact that surplus water in Ülemiste Lake discharged into the overflow channel during heavy rainfall. Generally, summer is the low rain season.

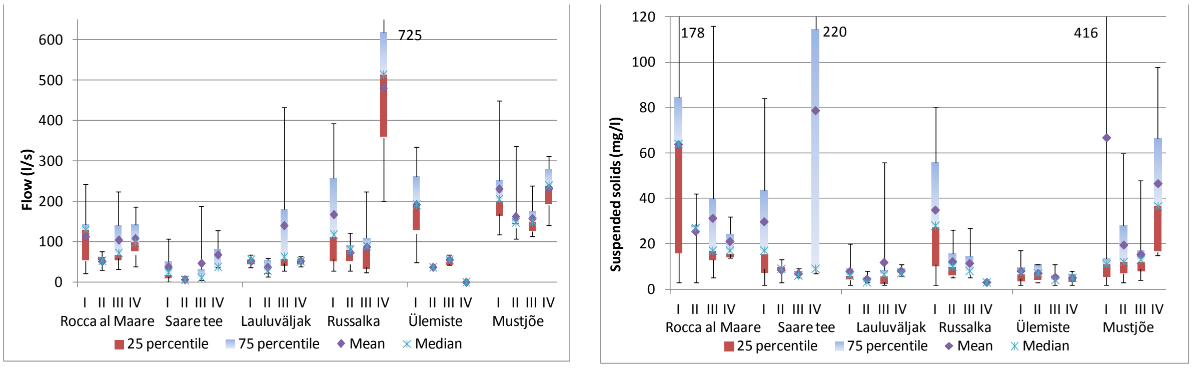

Figure 3: Variation of flow (left) and SS (right) for spring (I), summer (II), autumn (III) and winter (IV)

The emission of SS depends on storm event duration and intensity, antecedent dry days and impervious surfaces. Large storm events do not necessarily develop into a large amount of SS, but the first flush is the main concern in this regard (Davis & McCuen, 2005). *Figure 3* (right) shows that all basins discharge high SS during the spring. This is likely due to the process of ice melting after a long accumulation of contaminants and washing off activities entering the nearest drains. In autumn, besides Mustoja and Saare Tee, all other basins discharge higher SS than in winter. The summer has less variability while autumn and winter have a high variability in emissions.

Therefore, it is valid for all basins that the spring season is crucial for transporting SS but the same is hard to conclude for other seasons. Summer is more consistence, while autumn and winter are variable for discharging SS. From *Figure 3*, it is clear that half of flows greater than the median values are distributed over a large range. In other words, there is a huge bias towards the upper part. The same result can be noticed in the suspended solid concentration.

Accuracy of Means

The mean of flow and concentration is of great value in estimating total volume and mass emission from the drainage area. *Figure 4* shows a coefficient of variance (CV) for various monitored stormwater parameters for different drainage basins. A CV greater than 1 has a higher variation than mean. Flow, SS, TP and microbiological parameters have greater variation in data than mean, while other parameters have less variability.

Table 4 seeks to determine how much deviation of mean could occur in the analysis of the existing data. Positive and negative CI for mean of flow, conductivity, SS, BOD$_7$, TN and TP are calculated according to a range from 99% (p-value 0.01) to 70% (p-value 0.3) confidence levels. The mean parameters at 99% confidence interval could vary up or down 18.8 - 161.6% (flow), 26.3 - 56.7% (conductivity), 36.2 - 106.9% (SS), 28.7 - 72.6% (BOD$_7$), 12.5 - 57.3% (TN) and 27.0 - 64.8% (TN) depending upon the drainage area. Although confidence widths at 70% confidence interval are comparatively narrow, they still vary by plus minus 7.6 - 30.6% (flow), 10.6 - 22.8% (conductivity), and 14.6 - 43.03% (SS) 11.6 - 29.2% (BOD$_7$), 6.3 - 23.1% (TN) and 10.9 - 26.1% (TP).

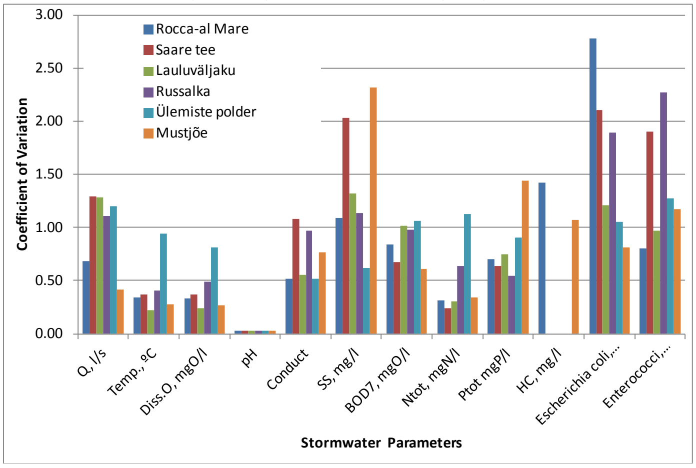

Figure 4: Coefficient of variance of parameters

Table 4: Deviation of mean between two confidence intervals

S. Sit	p-value	Q, l/s		Conductivity, mS/cm		SS, mg/l		BOD7, mgO/l		Ntot, mgN/l		Ptot mgP/l	
		Mean	**CI**	**Mean**	**CI**	**Mean**	**CI**	**Mean**	**CI**	**Mean**	**CI**	**Mean**	**CI**
1	(0.01-0.3)	95.84	[(+\-)36.78% to (+\-)14.8%]	818.26	[(+\-)27.12% to (+\-)10.91%]	38.21	[(+\-)57.57% to (+\-)23.17%]	10.56	[(+\-)44.21% to (+\-)17.79%]	4.09	[(+\-)16.44% to (+\-)6.61%]	0.44	[(+\-)37.14% to (+\-)14.94%]
2	(0.01-0.3)	38.42	[(+\-)67.83% to (+\-)27.29%]	1420.52	[(+\-)56.74% to (+\-)22.83%]	22.79	[(+\-)106.94% to (+\-)43.03%]	6.89	[(+\-)37.71% to (+\-)15.17%]	4.61	[(+\-)12.5% to (+\-)5.03%]	0.44	[(+\-)33.6% to (+\-)13.52%]
3	(0.01-0.3)	80.47	[(+\-)75.95% to (+\-)30.56%]	1008.93	[(+\-)28.95% to (+\-)11.65%]	8.43	[(+\-)70.88% to (+\-)28.52%]	8.10	[(+\-)72.55% to (+\-)29.19%]	5.00	[(+\-)16.06% to (+\-)6.46%]	0.23	[(+\-)39.41% to (+\-)15.86%]
4	(0.01-0.3)	150.04	[(+\-)56.25% to (+\-)22.63%]	760.48	[(+\-)50.67% to (+\-)20.39%]	18.26	[(+\-)61.37% to (+\-)24.69%]	9.14	[(+\-)50.69% to (+\-)20.4%]	6.81	[(+\-)32.68% to (+\-)13.15%]	0.13	[(+\-)26.96% to (+\-)10.85%]
5	(0.01-0.3)	115.93	[(+\-)161.63% to (+\-)65.03%]	596.03	[(+\-)26.39% to (+\-)10.62%]	6.19	[(+\-)36.16% to (+\-)14.55%]	7.87	[(+\-)63.16% to (+\-)25.41%]	7.53	[(+\-)57.34% to (+\-)23.07%]	0.10	[(+\-)48.19% to (+\-)19.39%]
6	(0.01-0.3)	184.33	[(+\-)18.81% to (+\-)7.57%]	558.39	[(+\-)33.97% to (+\-)13.67%]	31.97	[(+\-)103.99% to (+\-)41.84%]	5.75	[(+\-)28.71% to (+\-)11.55%]	4.18	[(+\-)15.66% to (+\-)6.3%]	0.26	[(+\-)64.78% to (+\-)26.06%]

There is large uncertainty of mean even when the confidence level is reduced to 70% (*Table 4*). Among them, sampling site 6 (Mustoja) has a relatively narrow deviation of means except for SS and TP. The confidence interval width for concentration narrows as the sample size increased and does not decrease proportionately for more than seven samples (Leecaster et al., 2002). In this case, the sample size is comparatively high (32 samples), but the main influencing factor is the range of data. As in *Figure 4*, it has a large range of measurement, which also illustrates why means of TN have relatively low deviations. In summary, flow and SS have higher uncertainty than conductivity, BOD_7, TN and TP in both confidence levels. There is a significant decrease in confidence width from 90-70% but at 70% confidence level, there is still considerable uncertainty in the mean flow and concentrations.

The above results show the variability in the stormwater data according to the mean value. With such high variability, statistical inferences will be highly uncertain. Therefore, further scrutinisation of sampling method in terms of sampling size and frequency is performed.

Scrutinizing sample size and frequency

Rainfall is categorised based on the size of daily rainfall intensity (DRI). The percentage distribution of rainfall is deemed as small amount of 69%, medium amount of 27% and large amount of 4%. At least 20 samples out of 30 are required for monitoring five years during the snow-free period. To sufficiently address the small, medium and large amount of rainfall, 14, 5 and 1 samples are required, according to percentage distribution of rainfall. During the study period, sites 1 - 5 deficits required number of samples or sample size as shown in *Table 5*. In sampling site 1, nearly 50% small rainfalls are not addressed but it lacks totally the runoff measurements of large DRI. In sampling site 2 and 3, samples are mostly collected when small storms are occurring, but most of the samples in the medium and large daily rainfall are missing. Sampling site 5 has the worst sampling frequency because only some of the medium DRI samples are covered. Finally, sampling sites 4 and 6 are good in terms of sampling for medium and large DRI and also attained relatively better confidence interval. Also, they have relatively good measurements for small DRI. Thus it is noticeable that there is no sufficient sample size and most of flows are captured for small range of DRI (<5mm).

Understanding and quantifying first flush is necessary for predicting environmental impacts on receiving waters and for the efficient design of treatment practices. The first flush wash off usually has the highest concentrations of pollutants, so it is this flush that can prove detrimental to healthy waterbodies. The pollutant loads in runoff after this first flush (over 12 mm of runoff) are assumed to be much smaller and should not have a significant impact on downstream ecology (Davis & McCuen, 2005). As in *Table 5*, the antecedent dry days (at least 7 days) before the runoff starts are counted. The numbers of those days are 12, 6 and 1 with corresponding small, medium and large rainfall during the snow-free period. There is one such sample for each site in snow cover period, which has 0.7 mm of 24 hrs precipitation and has a higher amount of SS, but it is difficult to suggest on the basis of this data how much antecedent dry days and rainfall can affect SS in total. No sample was measured during the snow-free period that can address such antecedent dry days, so it is hard to estimate the contribution of SS due to first flush on total mass emission, and it is difficult to obtain the sample size required to address those SS. It could probably increase the mean concentration and ultimately increase not only the mass emission of suspended solids but also positively related nutrients and pollutants like phosphorus, BOD_7 and microbiological parameters.

Table 5: Categorized rainfall size and approximate number of flow samples corresponding to the rainfall range (negative denotes deficit and positive denotes surplus)

Actual DRI					Approx. samples						Deficit and Surplus						7 days Antecedent dry		
Range, mm	size	no of Rain days	% size of DRI	Reqd no. of sample	1	2	3	4	5	6	1	2	3	4	5	6	no of Rain days	% size of DRI	Sample addressing Antecedent dry days
< 5	Small	417	69%	14	6	12	11	10	0	10	-57%	-13%	-20%	-28%	-100%	-28%	12	3%	NA
5-20	Medium	163	27%	5	8	3	2	6	1	11	48%	-45%	-63%	11%	-82%	103%	6	4%	NA
> 20	Large	23	4%	1	0	0	0	1	0	2	-100%	-100%	-100%	31%	-100%	162%	1	4%	NA

Conclusion

In this study, the monitoring data was analysed to obtain stormwater quality and quantity status in the city of Tallinn. The pollutant concentrations are not very high, compared to surface water quality classes, the stormwater status could be classified as moderate, aside from microbiological parameters. However, it cannot be suggested that the impact from stormwaters are negligible because the maximum concentrations observed were quite high for those basins and the status of the coastal sea is estimated as moderate. The high values of the microbiological parameters refer to possible occurrence of sewage discharges in the stormwater system, except the Ülemiste polder. It is observed that the polder basins function well in minimising the stormwater pollutants, especially in relation to sedimentation.

In more than half basins, positive correlation is found between flow and SS (0.4 - 0.6) as well between SS and TP (0.4 - 0.95).There is significant decrease in confidence width from 99–70% but there is still considerable uncertainty in the mean flow and concentrations at the 70% confidence interval. Flow and SS have higher uncertainty than conductivity, BOD_7, TN and TP at both confidence intervals. The variability in the stormwater is significantly larger than the mean value. Samples to inadequately address the entire rainfall, absence of information for first flush and high variability of data are particular shortcomings of this monitoring programme. Therefore, the stormwater monitoring programme as well the data should be revised in order to use for the further management approaches.

The sampling time during a storm event is quite important in order to prevent variability and improve sample representativeness of grab samples. Meanwhile, flush concentration can also influence substantially in the calculation of mass emission. This sampling time varies with hydrology, impervious surface as well as topology and the basin soil characteristics.

Single storms can be efficiently characterised with small bias and standard error by taking 12 samples with flow proportioned composite samples. The uncertainty of the overall average concentrations becomes reasonably steady as more samples are collected. In all methods, composite samples are taken either to measure total flow or mean concentration for a storm event or both. These composite samples are minimally required to measure flow since it is totally dependent on storm events, thereafter to provide platforms for validation of data.

The rainfall data are fundamental inputs for the analysis of stormwater runoff. Accuracy is achieved when the rainfall station is near to a sampling site. In our study, it is 20 km from Tallinn city centre. It is recommended that installation of a recording rain gauge on site or as close to the sampling site as possible is essential.

Heavy metals are important pollutants from stormwater runoff. These pollutants are detrimental to the waterbodies. Also, salting activity in highway for snow melting provides chlorides ions in the discharges. Proper monitoring of these metals and ions should also be included in the stormwater monitoring programme.

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