Impact of rainfall on bathing water quality – a case study of Fiskevollbukta, Inner Oslofjord, Norway

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Sammendrag

Effekt av nedbør på badevannskvalitet i Fiskevollbukta, Indre Oslofjord

Fiskevollbukta er en badeplass og turområde i Indre Oslofjord. Ljanselva renner ut i bukta og vannkvaliteten kan påvirkes av utslipp fra kloakkoverløp. Hensikten med studiet var å undersøke konsentrasjonen av fekale indikatorbakterier (*Escherichia coli*, termotolerante koliforme bakterier (TKB) og intestinale enterokokker) i Ljanselva og ved to badelokaliteter nær bukta etter ulike nedbørhendelser. Ved svabergene nær elvemunningen var badevannskvaliteten generelt dårlig i henhold til EUs badevannsdirektiv. Ved en liten strand omtrent 130 meter fra elvemunningen var derimot badevannskvaliteten tilstrekkelig basert på prøver tatt alle dagene, mens den var utmerket hvis man utelot prøver tatt fra dager med >10 mm nedbør i de siste 24 timer før prøvetaking. To generelle råd kan derfor redusere risikoen for mage-/tarmsykdom hos folk som bader i området: 1) Unngå bading ved elvemunningen 2) Unngå bading 24 timer etter kraftig nedbør.

Summary

The bay Fiskevollbukta is a popular recreational area in the Inner Oslofjord. The river Ljanselva flows into the bay and the water quality may be affected by sewer overflows (CSOs). The purpose of this study was to investigate concentrations of indicators of faecal pollution (*Escherichia coli*, faecal/thermotolerant coliforms and intestinal enterococci) in the river Ljanselva and at two bathing localities in the bay. The bathing water quality approximately 90 m from the river mouth was classified as poor according to the EU bathing water directive. At a little beach (about 130 m from the river mouth) the bathing water quality was sufficient based on all samples and excellent when data from days with >10 mm precipitation last 24 hours were disregarded. Two general advices may therefore reduce the risk of gastroenteritis of people bathing in the area: 1) Avoid bathing near the river outlet 2) Avoid bathing 24 h after heavy rainfalls.

Introduction

An important goal is to provide good hygienic bathing water quality at designated beaches in the Inner Oslofjord during the bathing season. Several measures have been implemented in recent years in order to reduce the sewage loads to the fjord, but external pressure from an increasing population, coalescing urban areas and more heavy precipitation the last summers is to some extent counter acting the measures (Vogelsang *et al.*, 2010; Daviknes, 2012). More precipitation may affect the local loads of faecal microorganisms to the fjord, e.g. due to discharges from combined sewer overflows (CSOs) and urban and rural surface runoffs (Tryland *et al.*, 2011). A further development of the inner harbour area into living- and recreational areas is also a challenge for the Oslo city authorities. This development requires good bathing water quality in a historically heavily polluted area.

The EU bathing water directive (EU, 2006) is not implemented in Norway, but many Norwegian municipalities use it as a guideline in their bathing water surveillance. The EU bathing water directive includes *Escherichia coli* and intestinal enterococci as indicator parameters for predicting microbiological health risk, but some Norwegian municipalities still use faecal/theromotolerant coliforms (FC). Most of the FCs that are detected in surface water are assumed to be *E. coli*, but other FCs, including some species of *Enterobacter* and *Klebsiella* that may multiply in the environment, may also contribute. FC is therefore not a sure indicator of faecal pollution, although in fresh water a good correlation between FC and *E. coli* is often observed (Tryland *et al.*, 2012). The faecal indicator bacteria are generally not pathogenic themselves, but indicate faecal contamination and potential presence of pathogenic bacteria, virus and parasites. Several studies have shown that faecal contamination in recreational waters is associated with an increased risk of gastrointestinal illness and less often also respiratory illness (WHO, 2003). Enterococci are recommended as indicator of faecal contamination in marine water by the United States Environmental Protection Agency (EPA, 2012) and the World Health Organization (WHO, 2003). According to the EU bathing water directive, results from the microbiological analysis from the last 4 years should be included for calculating 90 and 95 percentiles, which are used to classify the quality status of the bathing waters, table 1.

According to the EU directive at least 4 samples should be analysed every bathing season following a pre-set schedule. Monitoring shall take place no later than four days after the date specified schedule. The results from up to 15% of the samples, or maximum 1 sample per bathing season, may be disregarded because of short-term pollution. Short-term pollution is defined in the EU directive as microbiological contamination that has clearly identifiable causes and is not normally expected to affect bathing water quality for more than approximately 72 hours. Under short-term pollution the authorities must, if necessary, warn the public against bathing. Adequate management measures should be taken to prevent, reduce or eliminate the causes of pollution. If it is necessary to replace a disregarded sample, an additional sample should be taken seven days after the end of the short-term pollution (EU, 2006).

Historical data from the bathing water surveillance shows that most beaches in the Inner Oslofjord have excellent or good bathing water quality (Daviknes, 2012), while the water quality at some beaches is classified as poor. These beaches are generally located near CSOs, emergency overflows or the outlet of contaminated rivers. The water quality is not always poor, but varies widely, depending on discharges from CSOs during heavy rain, other faecal discharges, the location of the beaches relative to the discharges,

Parameter	Excellent quality	Good quality	Sufficient	Poor
Intestinal enterococci (cfu/100 ml)	≤100 (*)	101-200 (*)	≤185 (**)	>185 (**)
Escherichia coli (cfu/100 ml)	≤250 (*)	251-500 (*)	≤500 (**)	>500 (**)

(*) Based upon a 95-percentile evaluation
(**) Based upon a 90-percentile evaluation

Table 1. Classification of bathing waters according to the EU-directive. For coastal and transitional waters.

and on the tides and wind which affect the transport in the fjord. For such localities, results from weekly grab samples of water are of little value for the day to day recommendations regarding the hygienic safety of the water. Even daily water sampling may be misleading since the water quality may change quickly and the results from traditional microbial analysis are not ready before the next day. For better real-time advice as well as for prioritizing measures, a better understanding is requested of the effect of different faecal discharges on the water quality at designated beaches. The objective of this study was to investigate the loads of faecal indicator bacteria from the river Ljanselva during different weather conditions. The intention was also to show how rainfall episodes affect the hygienic bathing water quality in the area Fiskevollbukta, and finally to investigate whether a general advice against swimming 24 hours after heavy rainfalls is a useful approach for protecting public health.

Materials and methods

Study area and sample collection

Oslo, the capital of Norway with about 600 000 inhabitants, is located around the inner part of the Oslofjord (Figure 1). The Inner Oslofjord is recipient for treated wastewater and discharges from CSOs, but is also a popular area for recreational activities, e.g. at the little bay Fiskevollbukta, which is located at the eastern side of the Inner Oslofjord, figure 1. A river, Ljanselva (average water flow 0.6 m^3/s), which is recipient for discharges of CSOs during heavy rainfalls, flows into Fiskevollbukta. Two CSOs also discharge direct into the bay, figure 2. Other sources of faecal contamination in the bay include birds (mainly seagulls, goose and swans), dogs and leisure boats.

Water samples (500 ml) were collected at 3 different stations, figure 2, in a shallow water area (<1 m depth) within 130 m from the outlet of the river. For the river samples (station 1) the water samples were taken at the surface. For the bathing water samples (station 2 and 3, approximately 90 and 130 m from station 1) the samples were taken directly in the bottles by holding the bottles about 30 cm beneath the surface in water that was about 40 cm deep. Samples were taken 27 times during the period May 28th to August 27th 2013, generally at 8-9 a.m. Sample days were selected to reflect a typical Norwegian summer with both sunny and rainy days. Before and after heavy precipitation on June 27th (30 mm precipitation in 24 h) samples were taken 8 consecutive days to follow the effect of this event on the bathing water quality. After sampling, the water samples were immediately transported to the laboratory and analysed for indicators of faecal pollution within 2-3 hours. Four samples were also taken from a little stream (Lusetjernbekken) which also flows into Fiskevollbukta, but since the concentrations of faecal indicator bacteria in this stream in general were lower than in the river Ljanselva and the water flow was about 10 times lower, these data are not further presented.

Data on precipitation at 3 weather stations near Fiskevollbukta (Ljabruveien, Lambersteter and Bygdøy) were collected from the Norwegian Metrological Institutes webpage (www.eklima.no). Average precipitation observed at the 3 weather stations was used for further data presentation. Information about the wind direction was taken from the Blindern weather station (www.eklima.no).

Data on water flow in the river Ljanselva was obtained from Oslo municipality.

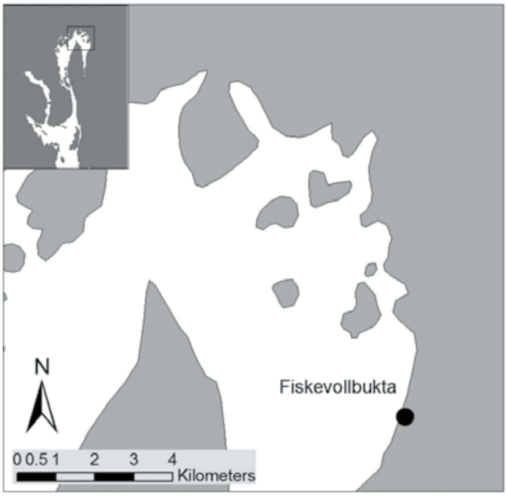

Figure 1. Fiskevollbukta is located in the Inner Oslofjord.

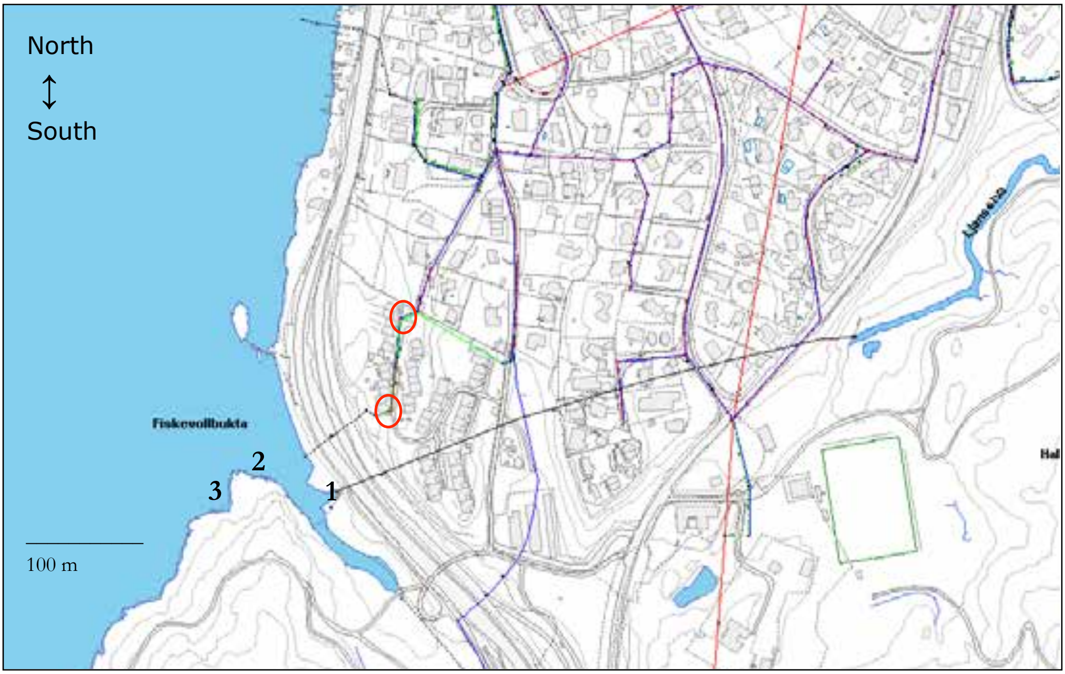

Figure 2. Water samples were collected at 1) the outlet of Ljanselva (the water is transported in a pipeline/tunnel last 400 m before the outlet), 2) at some rocks approximately 90 m from the river mouth and 3) at the little beach close to the bay approximately 130 m from the outlet of the river. Discharges from CSOs direct to the fjord are marked with red circles (Oslo VAV).

Bacterial analysis

E. coli was enumerated using the IDEXX Colilert 18® Quanti-Tray/2000 method (ISO 9308-2). As specified in the standard the marine water samples were diluted 1:10 in sterile distilled water before analysis. The results are given as most probable number (MPN). Intestinal enterococci and faecal (thermotolerant) coliforms were quantified after membrane filtration using the ISO 7899-2 method and the NS 4792 method, respectively. The results are given as colony forming units (cfu).

Calculation of 90 and 95 percentiles

The bathing water quality was classified based on percentile evaluation of the $\log_{10}$ normal probability density function of microbiological data acquired from the particular bathing water, as specified in the EU bathing water directive (EU 2006). The percentile value was derived as follows: i) Take the $\log_{10}$ value of all bacterial enumerations in the data sequence to be evaluated, ii) calculate the arithmetic mean of the $\log_{10}$ values (μ), iii) calculate the standard deviation of the $\log_{10}$ values (σ). The upper 90 percentile point of the data probability density function is derived from the following equation: upper 90-percentile = antilog (μ + 1,282σ). The upper 95-percentile point of the data probability density function is derived from the following equation: upper 95 percentile = antilog (μ + 1,65σ).

Results and discussion

The concentrations of faecal indicator bacteria in the outlet of the river Ljanselva was found to vary from about 200 – 8000 per 100 ml, table 2. This is not very high values compared with other urban rivers, but too high to be sufficient as bathing water without dilution and bacterial die-off which occur when the river water is discharged into the fjord. The concentrations of faecal indicator bacteria in the river showed no clear correlation with the observed precipitation 24 h before sampling, since high values were also measured after some days with little precipitation, table 2. But, the water flow in the river increased during periods with much precipitation. River runoff ranged from 0.02-3 m^3/s (hourly values) during the test period, and the calculated loads of faecal indicator bacteria from the river therefore increased after heavy rainfalls. From June 26th (after a dry period) to June 27th (30 mm precipitation last 24h), the loads of *E. coli* and intestinal enterococci increased by about 1.5 log_{10}, figure 3.

Date	Precipitation (mm/24 h)	1. River Ljanselva			2. Rocks			3. Little beach		
		FC*	*E.coli***	Int. Ent*	FC*	*E.coli***	Int. Ent*	FC*	*E.coli***	Int. Ent*
28.05.2013	5,8	1800	2400	no data	1700	2100	no data	6	10	no data
29.05.2013	2,7	300	280	670	840	120	1100	1	<10	<10
30.05.2013	1	270	300	640	200	280	130	20	20	9
03.06.2013	10,6	1500	1800	630	1800	2200	1300	2300	1700	2100
10.06.2013	1,3	900	780	270	20	10	1	5	10	2
26.06.2013	0	530	730	300	400	380	40	350	410	<10
27.06.2013	30,3	3100	3900	760	2500	2800	830	50	40	40
28.06.2013	1,2	1200	1700	400	1500	1800	310	100	10	<10
29.06.2013	0,8	820	1000	210	390	370	70	<10	10	<10
30.06.2013	11,9	950	910	240	350	500	170	480	430	340
01.07.2013	0	360	360	110	270	280	100	<10	10	10
02.07.2013	0	940	500	940	410	90	410	<10	10	<10
03.07.2013	1,2	680	650	130	250	230	150	100	20	<10
09.07.2013	0	330	340	360	10	30	100	30	20	10
15.07.2013	0,1	890	910	120	20	20	<10	10	<10	10
22.07.2013	0	880	1400	200	100	590	30	<10	20	10
29.07.2013	0,2	770	990	250	140	130	20	100	40	30
01.08.2013	4,2	390	650	300	320	350	140	<10	<10	20
02.08.2013	0,1	940	1200	580	340	290	280	60	100	10
03.08.2013	1,8	7300	7700	1800	500	630	240	90	160	120
04.08.2013	12,7	1100	1900	520	700	120	250	110	40	40
05.08.2013	4,9	1400	1700	780	150	130	90	<10	20	20
06.08.2013	5,6	1980	1291	1020	200	120	180	50	170	160
07.08.2013	4,1	1000	1200	390	430	460	370	60	90	130
22.08.2013	0	1000	1500	210	30	30	90	10	<10	10
26.08.2013	0	1300	1900	1300	90	100	110	<10	<10	20
27.08.2013	0	620	860	960	10	60	50	<10	10	20

*cfu/100 ml **MPN/100 ml

Table 2. Measured concentrations of faecal coliforms (FC), E. coli and intestinal enterococci (Int. Ent) in the outlet of river Ljanselva (1), at the rocks near the river mouth (2), and at the little beach (3). The precipitation 24 hours before each sampling day is presented. Green background indicates excellent -, yellow indicates good - and red indicates poor bathing water quality according to the 95 percentiles in the EU directive.

On June 27th after the 30 mm precipitation, the numbers of faecal indicator bacteria were high in the river and at the rocks/river mouth, but low at the beach, table 2. The wind direction was from east (85°) this day, which probably generated currents out from the bay and therefore a lower transport of contaminated water to the beach. The measured water quality was generally good at the beach, except at the two sampling days June 3rd and June 30th, which were days after >10 mm precipitation and with wind from north (13° and 26°). This wind direction may have enhanced the transport of contaminated brackish water from the river mouth down to the beach which is located in the southern direction, figure 2. In general, for beaches located near the outlet of contaminated rivers, the direction of the surface currents may strongly affect how the beach water is influenced. The direction of the surface currents depend on the tides and the wind. The magnitude of the water flow from the river also plays a role, as well as the topography/bottom conditions, and due to the Coriolis-force the overall movements tend to the right (on the northern hemisphere). The water sampling at the beach at Fiskevollbukta indicated that the wind direction strongly influenced how the beach was affected by the rainfall-induced loads of faecal microorganisms to the bay. The importance of the wind direction is also observed at other beaches in the Inner Oslofjord and will be modelled and presented in future papers (Tryland and Tjomsland (NIVA) unpublished).

In addition to discharges from the river, CSOs and other faecal sources in the area and the dilution due to water currents, the measured water quality in the bay and at the beach also depend on the bacterial die-offs. Intestinal enterococci are shown to survive longer than *E. coli* in marine water and are the recommended indicator by the United States Environmental Protection Agency (EPA, 2012). According to the EU directive both *E. coli* and intestinal enterococci have to be measured and the classification should be done based on the parameter indicating the poorest class.

Calculation of 90 and 95 percentiles, based on data from the 27 samples, and classification according to the EU bathing water directive showed good water quality at the beach with regard to *E. coli* and FC. This is in agreement with the classification done by the routine measurements performed by the Oslo city, based on FC data from last 4 years (Daviknes 2012). The percentile values calculated from the FC data were slightly higher than the values calculated

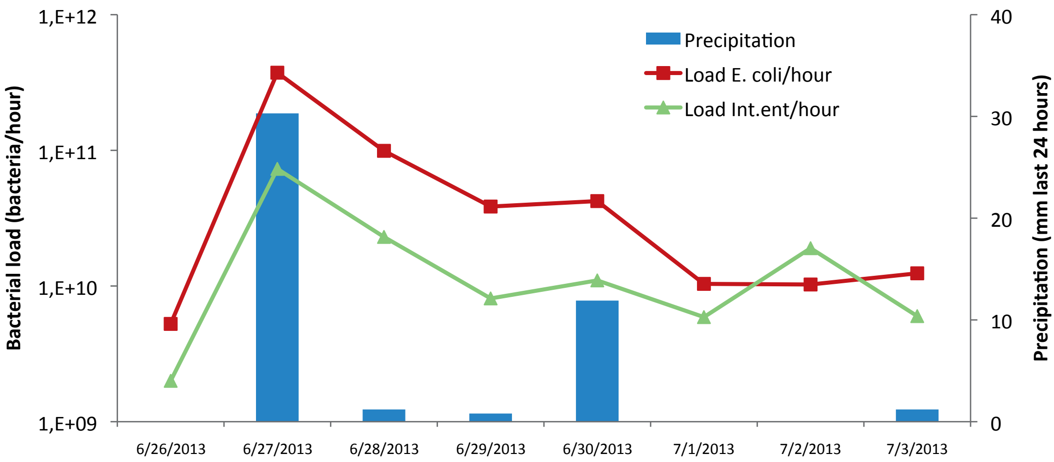

Figure 3. Loads of E. coli and intestinal enterococci (bacteria per hour) from the river Ljanselva after different precipitation conditions. The loads are calculated based on the measured concentrations in the river from daily samples and the measured water flow (hourly value) when the samples were taken.

from the *E. coli* data, indicating that use of FC instead of *E. coli* is conservative and may rather underestimate, than overestimate the quality status of the bathing place. The Intestinal enterococci data, however, only indicated sufficient water quality at the beach, when all data were included, table 3. Oslo city authorities may therefore consider to also include intestinal enterococci in the routine monitoring program, in agreement with the EU bathing water directive.

When data from days with >10 mm precipitation before water sampling was excluded from the calculation of 90 and 95 percentiles, the water quality at the beach was excellent according to all the indicator bacteria, table 3. A general advice against swimming 24 hours after heavy rainfalls, which is already posted at the Oslo city bathing water webpage, is therefore a useful advice for preventing exposure of bathers to pollution. Also the calculated 90 and 95 percentiles from the samples taken at the rocks near the river mouth were improved when data from days with >10 mm precipitation last 24 h were disregarded, table 3, although the water quality was still poor according to the EU classification, table 3.

Conclusions

The loads of faecal indicator bacteria from the river Ljanselva to Fiskevollbukta was in general shown to increase after heavy rainfalls, but since the dilution due to a higher water flow also increased, the concentrations measured in the river were not clearly correlated with the precipitation 24 hours prior to sampling. The water quality at the rocks near the river mouth was classified as poor according to the EU bathing water directive both with regard to *E. coli*, FC and intestinal enterococci, also when the water samples taken after >10 mm precipitation last 24 hours were disregarded. The water quality at the little beach (approximately 40 m from the rocks) was classified as good with regard to *E. coli* and FC and sufficient according to intestinal enterococci when all data were included. When data from days with >10 mm precipitation was disregarded, the water quality at the beach was excellent according to all the faecal indicators. Two general advices may therefore reduce the risk of gastroenteritis of people bathing in the area: 1) Avoid bathing near the river outlet, 2) Avoid bathing 24 h after heavy rainfalls. The results also show that water quality based on indicators of faecal pollution may be quite different within small distances.

Acknowledgements

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	2. Rocks			3. Beach		
	FC*	*E. coli***	Int. Ent*	FC*	*E. coli***	Int. Ent*
90 percentile (all data)	1548	1380	812	245	195	148
95 percentile (all data)	2754	2340	1410	457	331	257
Classification(all data)	Poor	Poor	Poor	Good	Good	Sufficient
90 percentile (>10 mm disregarded)	1071	977	602	110	98	58
95 percentile (>10 mm disregarded)	1905	1584	1023	182	147	83
Classification (>10 mm disregarded)	Poor	Poor	Poor	Excellent	Excellent	Excellent

*cfu/100 ml
**MPN/100 ml

Table 3. Classification of quality status according to the EU directive, when all data were used and when samples taken after >10 mm precipitation were disregarded.

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