sweden water research

Urban Swimming

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Urban Swimming

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Sweden Water Research, 2025

List of content

Summary

The Urban Swimming project explored the causes of poor bathing water quality at beaches in Helsingborg and Inner Children's Bay (Inre Barnviken), Malmö. Innovative methods for real-time monitoring of water quality were also tested.

Sources of Contamination at Inner Children's Bay, Malmö

At Inner Children's Bay, faecal indicator bacteria have been persistently reported, resulting in frequent poor bathing water quality. Hammarsbäck stream and its source, the Limhamn quarry, were initially suggested as contamination sources. However, research in Hammarsbäck from source to end revealed the primary source of contamination is located downstream in Hammars Park. The exact contamination source remains unknown.

Bathing Water Quality in Helsingborg

In Helsingborg, poor water quality is sometimes observed during dry weather, indicating additional sources beyond stormwater or surface runoff. Resuspension of contaminated sediments as a possible explanation was investigated. Sediments from Helsingborg's beaches harbour faecal indicator bacteria, some of them possibly harmful, likely originating from multiple sources, including treated wastewater effluent. Significant variations in water quality exist between neighbouring beaches.

Real-time Monitoring of Bathing Water Quality

Traditional bacterial cultivation methods take several days to produce results. The project tested two rapid alternatives: online monitoring of faecal indicator bacteria and flow cytometry.

Both methods show promising results, providing measurements within just a few minutes. However, direct comparison with standard methods is challenging due to differences in methodology. In particular, flow cytometry measures all bacteria rather than specific types, making it unclear how the results can be effectively utilised for bathing water monitoring. To address this, machine learning is being employed to assist in evaluating the data. Additional challenges include the need for dedicated infrastructure and personnel, as well as the practical difficulties of operating the equipment in a coastal environment, especially during storms.

About the Urban Swimming Project

The Urban Swimming project, led by Sweden Water Research since 2020, investigated bathing water issues in Helsingborg and Malmö. It was conducted in collaboration with Catherine Paul at Lund University as scientific leader, Kristianstad University, and with the support of NSVA, VA SYD, City of Malmö and City of Helsingborg.

Background

Recreational water use, including bathing, is a popular activity during summer in both coastal and inland areas. Monitoring bathing water quality is crucial to prevent health risks associated with poor water quality (WHO 2021). In Sweden, the microbiological quality of bathing water is regulated under the European Bathing Water Directive (Directive 2006/7/EC) and Swedish regulations (HVMFS 2012:14), using *Escherichia coli* (*E. coli*) and intestinal enterococci as indicators of faecal pollution.

Improvements in bathing water quality across Europe have been achieved due to these regulations (EEA, 2020). However, limitations in current microbiological monitoring approaches persist:

- Although poor water quality can be identified at a bathing location, the underlying causes are often unclear without further investigation.
- Standard methods rely on culturing bacteria, causing delays of several days between sampling and reporting results (Demeter et al., 2020).
- Contamination events of short duration may result in inaccurate assessments of water quality, as the sampling frequency for water monitoring may be insufficient to detect them. (Boehm, 2007).

In southern Sweden, poor bathing water quality has been repeatedly reported for beaches along the Öresund. This is the case for Inner Children's Bay in Malmö, and coastal beaches in the urban area of Helsingborg. At Inner Children's Bay, bathing water quality has been problematic for many years. Previous research pointed to Hammarsbäck stream and the the Limhamn quarry as potential sources of contamination. For Helsingborg, contamination is sometimes observed during dry periods, suggesting unknown sources. Marine sediments have been identified as a possible reservoir for faecal indicator bacteria (Paul et al., 2019).

From August 2020, the Urban Swimming project, led by Sweden Water Research, investigated these issues. The project expanded on earlier studies conducted at Lund University (Paul 2019, Frank 2020, Persson 2020). During the project, investigations into the sources of poor water quality were conducted for both Helsingborg and Children's bay, alongside an exploration of online monitoring methods for bathing water quality.

Results summarised in this report aim to provide insights accessible to both scientific and general audiences. Results from scientific studies still unpublished at the time of the writing of this report (October 2024) are only briefly mentioned in here, as analysis and interpretation of results is ongoing.

Investigation of Sources for Poor Bathing Water Quality

This section is divided into two parts, corresponding to the two study sites investigated in the Urban Swimming project: Inner Children's Bay and Helsingborg.

Inner Children's Bay

Key Points

Faecal indicator bacteria counts exceeding legal limits are frequently reported, resulting in a permanent bathing prohibition and deregistration as an EU beach.

- Hammarsbäck stream, which discharges into Children's bay, and its source, the Limhamn quarry, were previously suspected as potential sources of contamination.
- Detailed sampling campaigns conducted during 2022 and 2023 identified high concentrations of *E. coli* in Hammarsbäck.
- The Limhamn quarry was ruled out as a major source of *E. coli* in Hammarsbäck. Instead, the contamination appears to originate downstream in Hammars Park.
- The *E. coli* at Hammarsbäck not only represents an indirect health risk to the public as indicators for faecal contamination but is also a potential direct health risk to bathers.
- Given the uncertainties in the origin of *E. coli*, and the potential risks to bathers, we recommend that the bathing prohibition at Inner Children's Bay continues.

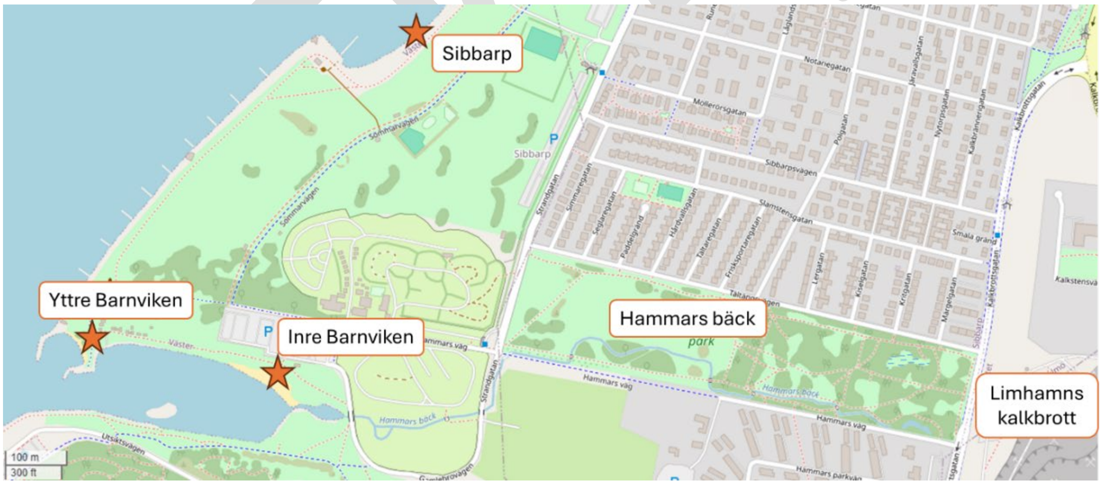

Figure 1. Map of Children's bay and Hammarsparken. Modified from OpenStreetMap (accessed on 2024-08-29). Beaches are indicated with a star.

Problem

Poor bathing water quality has been a persistent issue at Inner Children's Bay, with high levels of faecal indicator bacteria leading to frequent closures and extensive media coverage. Ultimately, the beach was deregistered as an EU bathing site.

Unlike nearby beaches, such as Outer Children's Bay and Sibbarp, which generally report good water quality, contamination at Inner Children's Bay appears to be localised. Hammarsbäck, a stream originating from the Limhamn quarry, was suggested as a contamination source. Water is actively pumped from the quarry to prevent flooding, and the stream flows through Hammars Park before discharging into Children's bay.

Research

To investigate whether Hammarsbäck contributes to contamination at Inner Children's Bay, a series of surveys were conducted during 2022 and 2023 in collaboration with Lund University. These included:

- Sampling at multiple points along Hammarsbäck from its source to its discharge point: at Outer Children's Bay, Inner Children's Bay, the Hammarsbäck estuary and the Limhamn quarry (Erb, 2022b). More detailed and frequent sampling at different points along Hammarsbäck were done during 2023 (Dwita 2023, Dwita 2024).
- Detailed analysis of *E. coli* concentrations in the stream (Dwita 2024).
- Assessments of potential health risks posed by *E. coli* strains found in Hammarsbäck (Dwita 2024).
- Statistical analysis incorporating weather data to identify potential correlations with water quality (Gullberg 2024).

Figure 2: Concentrations of the faecal indicator bacteria *Escherichia coli at* Hammars back. Only the highest observed values during the 2022 and 2023 surveys are shown.

Conclusions

By sampling along the entire length of Hammarsbäck, from its source to its endpoint, it was found that:

- The poorest water quality (i.e., the highest concentrations of E. coli) was found in the stream, suggesting that the downstream flow of contaminated water is a significant factor affecting the bathing water quality at Inner Children's Bay.

- As *E. coli* concentrations were low at the quarry and in the upper course of Hammarsbäck, the quarry is unlikely to be the main source of *E. coli* contamination in Hammarsbäck and Inner Children's Bay.
- In Hammarsbäck, the location with the poorest water quality was identified south of Hammarspärk, near a pedestrian bridge where water stagnation occurs (Figure 3). This indicates that sources of contamination may be nearby and that the conditions in this part of the stream might promote poor water quality.
- For the 2023 bathing season, no clear links were observed between weather conditions and water quality at Hammarsbäck. However, earlier in the spring, increased water temperatures and precipitation appeared to correlate with higher *E. coli* concentrations.
- Some *E. coli* strains found in Hammarsbäck exhibited antibiotic resistance and potential virulence, signalling a possible health risk to the public.

Figure 3: Location with the poorest water quality at Hammarsbäck during 2023. Southwest of Hammars park (55° 34' 17.816" N, 12° 54' 46.056" E)

Helsingborg

Key Points

- Poor bathing water quality is occasionally reported at several beaches. Resuspension of contaminated sediments has been suggested as a possible explanation for this.
- As part of the Urban Swimming project, sediment and water samples were collected in Helsingborg between 2019 and 2021.
- The faecal indicator bacteria *E. coli* was detected in coastal marine sediments in Helsingborg.
- Multiple sources of contamination exist for the sediments, including effluents from both treated and untreated sewage sources (WWTP and CSO), as well as likely contributions from other sources.
- Some *E. coli* strains in the Helsingborg sediments represent not only an indirect health risk to the public as indicators of faecal contamination but also a potential direct health risk to bathers.
- Preliminary research suggests that contamination patterns at Helsingborg's beaches are local, meaning distinct sources of contamination or specific conditions favouring poor water quality exist even between neighbouring beaches.

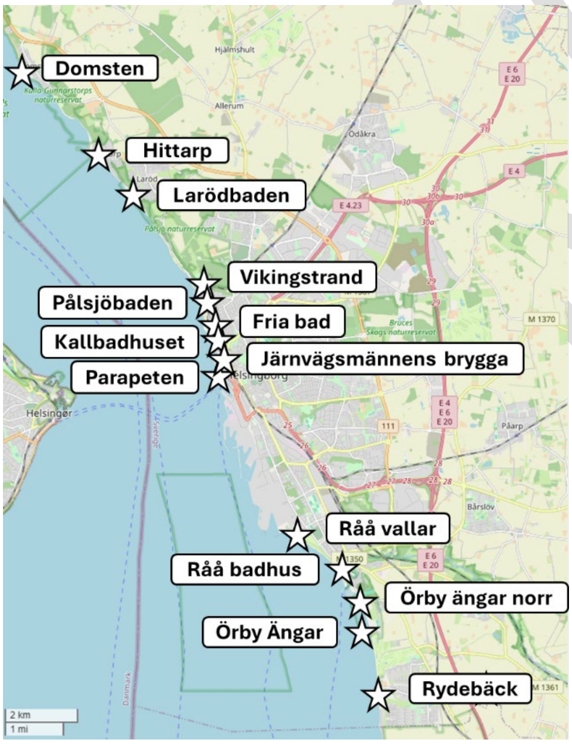

Figure 5: Location of EU beaches in Helsingborg along the Öresund. Modified from OpenStreetMap (accessed on 2024-08-29). Beaches are indicated with a star.

Problem

Between 2010 and 2024, there were multiple instances at Helsingborg's beaches where concentrations of faecal indicator bacteria were alarmingly high, exceeding the limits for suitable bathing water (Figure 6). These incidents occurred across most of Helsingborg's EU-designated beaches but were particularly frequent at Vikingstrand, Hittarp, and Fria Bad. The number of occurrences was notably high in 2018 and 2019 (data from HaV), resulting in advisories against bathing and extensive media coverage (Hjortsman, 2018; Sköldqvist, 2019).

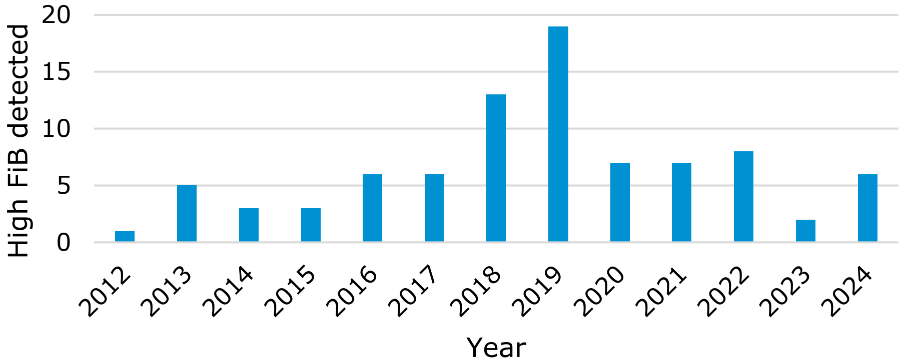

Figure 6. Number of instances between 2010 and 2024 where high concentrations of faecal indicator bacteria were reported in Helsinborg (*E. coli* > 1000 CFU/100ml or Enterococci > 300 CFU/ml). Data from HaV

Some of these events occurred during periods of low rainfall, suggesting that sources other than runoff, stormwater, and combined sewer overflow (CSO) events may be contributing (Paul et al., 2020). During drier periods, marine sediments have been proposed as reservoirs for faecal indicator bacteria. This hypothesis was supported by preliminary research that detected viable *E. coli* in the coastal sediments of Helsingborg (Paul et al., 2020; Frank et al., 2020). However, the source of the *E. coli* in these sediments was uncertain, and it was unclear whether they posed a risk to human health.

Research

Between 2019 and 2021, water and sediment samples were collected along the coast of Helsingborg. Sediment sampling was conducted during the spring and summer of 2019, 2020, and 2021 to investigate the sources of *E. coli* in the sediments, including any impact from the wastewater treatment plant in Helsingborg. These samples were taken from areas centred around the treatment plant's outlet, extending one kilometre south and three kilometres north of the outlet (Figure 7).

To gain a better understanding of contamination patterns at the beaches and identify possible causes, water sampling was conducted at all Helsingborg beaches during the bathing seasons of 2020 and 2021. For both water and sediment samples, *E. coli* concentrations were measured, and DNA sequencing was performed to characterise the microbial communities and facilitate source tracking (Hägglund et al., 2018). Laboratory experiments were also undertaken to provide a more detailed characterisation of the *E. coli* strains found in the sediments. Additionally, modelling of *E. coli* dispersal in sediments was performed. Finally, historical records of bathing water quality from 1995 to 2023 were analysed and compared with corresponding weather data from SMHI.

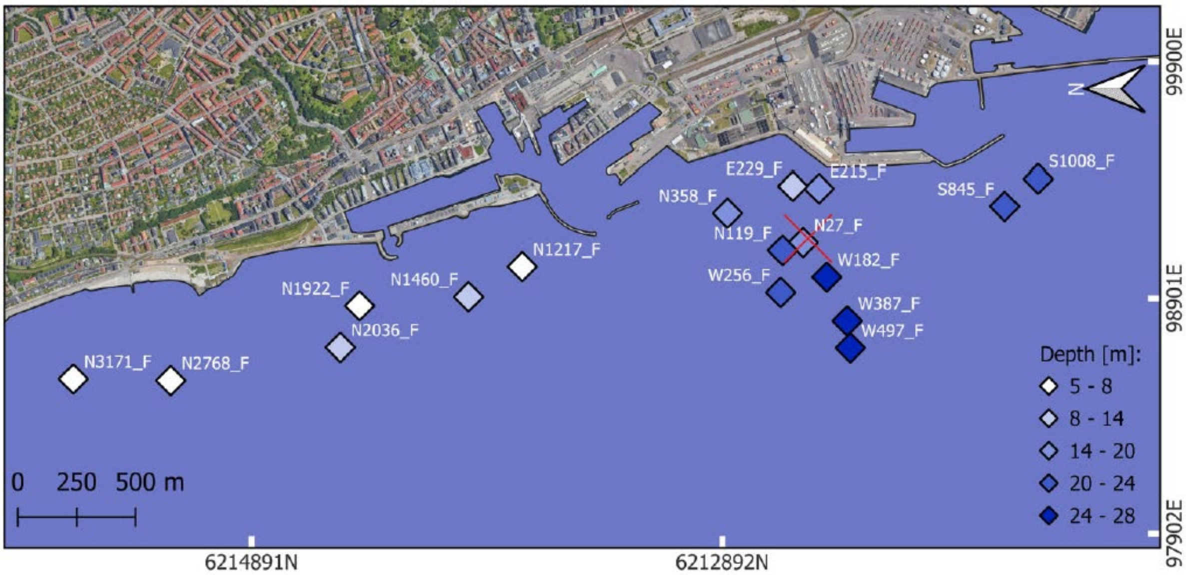

Figure 7. Sampling locations of sediments in Helsingborg. Numbers in the sample names indicate the distance in meters to the effluent of the wastewater treatment plant. Source: Erb et al (2024)

Conclusions

- Historical contamination patterns in the bathing water of Helsingborg have been localised, with neighbouring beaches sometimes exhibiting suitable and unsuitable water quality simultaneously. Beaches with consistently poorer water quality include Vikingstrand, Fria Bad, and Hittarp (Frank et al., 2025).
- Marine sediments in Helsingborg harbour the faecal indicator bacteria *E. coli*, making them a potential reservoir for these bacteria in bathing water (Frank et al., 2024; Erb et al., 2024). However, modelling predicts that the contribution from sediments to bathing water is minimal (Gudmundsson et al., 2024). This suggests that other sources of contamination must exist.
- *E. coli* and other bacteria associated with sewage were more abundant in sediments near the outlet of the wastewater treatment plant but were also detected up to three kilometres north of the outlet (Frank et al., 2024; Erb et al., 2024).
- Some *E. coli* strains in the sediments, particularly those close to the treatment plant's effluent, were found to be potentially pathogenic (Erb et al., 2024).
- Discharges from combined sewer overflows can temporarily contaminate sediments with bacteria from untreated sewage (Frank et al., 2024b).

- These findings indicate that both treated and untreated sewage releases (from the wastewater treatment plant and combined sewer overflows) contribute to sediment contamination. However, there is also evidence of other unknown sources of contamination (Erb et al., 2024; Frank et al., 2025).

Future outlooks

The relationship between bacteria in sediments and bathing water quality in Helsingborg remains poorly understood. It is also unclear why neighbouring beaches can exhibit drastic differences in water quality. Furthermore, the impact of weather and hydrological conditions is uncertain. As the factors contributing to poor bathing water quality in Helsingborg are largely unknown, this hinders the implementation of corrective measures and the development of early prevention systems.

A more comprehensive analysis of bathing water quality in Helsingborg is currently underway (Frank et al., 2025), with work still ongoing at the time of writing this report.

The use of online monitoring and machine learning to analyse water quality data is also being explored. These approaches may enhance our understanding of the conditions linked to poor bathing water quality and support the development of new and faster methods for water quality monitoring. This is discussed further in the next section.

Rapid Monitoring of Bathing Water Quality

Key Points

- Monitoring bathing water quality using culture-based standard methods is not always suitable for current status assessments, as results require several days to process.
- Online monitoring systems provide a rapid alternative, enabling frequent sampling.
- Two systems were evaluated: flow cytometry and online monitoring of faecal indicator bacteria.
- With automated sampling, measurements can be obtained within just a few minutes.
- Potential applications include the development of early warning systems, as well as utilising the data for statistical analysis and machine learning models.
- However, measurements obtained via these methods are not directly comparable to those from culture-based standard methods, and as such, they cannot replace standard methods.
- Dedicated personnel and infrastructure are necessary to operate online monitoring systems effectively.
- Further research is required to determine the suitability of flow cytometry for bathing water quality monitoring.

Background

The presence of faecal indicator bacteria in bathing water is regularly monitored using standard methods based on the culturing of these bacteria (Directive 2006/7, HVMFS 2012:14). This monitoring is employed for the long-term classification of bathing sites according to their water quality. It is also used to assess the current water quality status and, when necessary, to advise the public against swimming in poor-quality water (HaV, 2021).

For current status monitoring, culture-based methods have two significant limitations:

1. There is a delay of several days between sampling and obtaining results.
2. Samples are collected only a few times during the bathing season.

As a result, the water quality status represents a snapshot of conditions from several days earlier, rather than the actual conditions at the time of sampling. Since water quality can change rapidly (Boehm, 2007; Whitman et al., 2004), short-duration pollution events may go undetected.

There is a clear need for faster monitoring methods that can support urgent decision-making. The implementation of rapid methods, alongside frequent sampling several times a day, is desirable as it would improve the detection of short-duration pollution events. In Helsingborg and Malmö, two innovative methods were evaluated: online monitoring of faecal indicator bacteria and flow cytometry.

Online Monitoring of Faecal Indicator Bacteria

For the two bacteria used as faecal indicators, *Escherichia coli* (*E. coli*) and Intestinal enterococci, online monitoring was evaluated using the ColiMinder system (Vienna Water Monitoring Solution).

The device detects the activity of target bacteria within minutes using an enzymatic assay. Automated sampling enables frequent analyses at regular intervals.

Figure 8. ColiMinder and Bactosense at Pålsjöbaden

Installation and Sampling

During the bathing seasons of 2022, 2023, and 2024, one or two ColiMinder devices were installed at Pålsjöbaden (Helsingborg) to measure *E. coli* and intestinal enterococci. In 2023, two additional ColiMinder units were installed in Malmö. A flow cytometer was also deployed to analyse the same water samples, as discussed in the following section.

The machines were housed in enclosed structures to protect them from environmental factors. Water was pumped from the sea, and samples were taken every three hours in 2022 and every two hours in 2023 and 2024. Users could access the machines and their data through an online interface.

Results

Sampling at frequent intervals throughout the bathing seasons provided, for the first time, a detailed survey of bathing water quality at beaches along the Öresund. The microbial water quality was found to be highly dynamic, with faecal indicator bacteria activity sometimes fluctuating significantly within a matter of hours (Figure 9).

Overall, trends in *E. coli* and Intestinal enterococci activity, as measured by ColiMinder, were similar. This suggests that monitoring only one of these indicators may be sufficient for rapid assessments of bathing water quality.

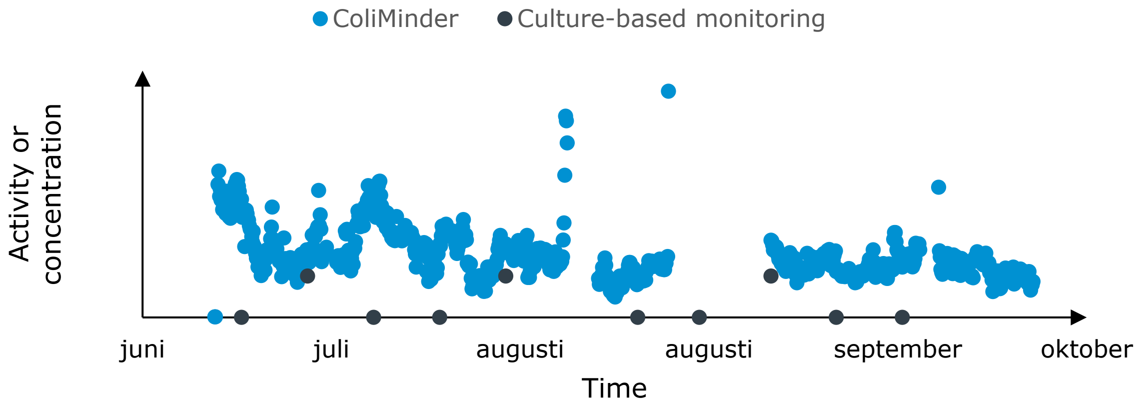

Figure 9: Comparison of sampling frequency for water quality measurements at an EU beach with regular monitoring (black, cfu/mL) and ColiMinder (blue, activity); every dot is a measurement.

Difficulties

One significant challenge with online monitoring of bathing water is the extensive infrastructure required to operate the machines. This includes not only structures to shield the devices from environmental conditions but also electric and hydraulic systems, such as water pumps, to ensure proper functioning.

The coastal environment presents additional difficulties for the machines and their infrastructure. The location's exposure to harsh conditions, such as storms, led to power outages, which disrupted data collection. Furthermore, limited and intermittent internet connectivity interfered with online access to the machines.

As the machines analyse seawater, which contains large particles, extensive water filtration was necessary. Filters required frequent cleaning, and the machines also needed periodic preparation and replenishment of solutions. As a result, operating the machines was labour-intensive and required dedicated personnel.

Many of these issues recurred during the various trials. Therefore, for future installations, it is strongly recommended to develop contingency plans prior to the bathing season to mitigate potential disruptions.

Limitations

The principles underlying culture-based standard methods and enzymatic methods, such as ColiMinder, differ significantly, meaning their measurements cannot be directly compared. According to current Swedish guidelines (HaV 2021), the threshold for unsuitable water quality is 1000 CFU/ml for *E. coli* and 300 CFU/ml for Intestinal enterococci in individual samples when using standard methods. Equivalent thresholds for enzymatic methods remain unclear, although comparisons with culture-based methods have been conducted in freshwater, and thresholds for other countries have been suggested (Cazals et al., 2020).

Additionally, the trends observed with enzymatic methods, like ColiMinder, may occasionally differ from those produced by culture-based methods. Enzymatic assays can detect faecal indicator bacteria that are not culturable (Garcia-Armisen et al., 2005). False positives may occur when non-target bacteria are detected (Fiksdal & Tryland, 2008). Specifically, some other faecal bacteria, as well as certain environmental bacteria, may contain the same enzyme targeted by the *E. coli* assay (Baudart et al., 2009; Demeter et al., 2020). At low concentrations of faecal indicator bacteria, these other bacteria may interfere with the assay (Demeter et al., 2020).

Finally, the trials were conducted at only one location in Helsingborg and one in Malmö. Both cities have extensive coastlines with numerous EU-designated beaches. It is unclear whether the water quality results from these single locations are representative of other beaches. For instance, where local contamination sources exist, significant differences in water quality may be observed between beaches in the same city. To obtain an accurate picture of overall water quality, the installation of multiple machines at various locations may be necessary.

Opportunities

Although enzymatic methods cannot replace culture-based standard methods, they could serve as a valuable complementary approach for current status monitoring. If abnormally high values are detected, manual samples can be collected and analysed using culture-based methods to confirm whether these values represent actual faecal indicator bacteria. In the interim, a precautionary closure of the beach might be recommended while awaiting confirmation.

The use of enzymatic methods for data collection could also enhance our understanding of how weather conditions influence water quality at beaches equipped with monitoring machines. This information could support the development of predictive tools for forecasting the presence of faecal indicator bacteria in bathing water.

Flow Cytometry to Assess Bathing Water Quality

Flow cytometry is a method that can measure all bacteria in a water sample to determine their total concentration and provide a DNA profile of the sample. Although the method cannot differentiate between harmful and non-harmful bacteria, it offers rapid measurements, and machines with automatic sampling capabilities are available. The extensive experience in its use at drinking water utilities in Skåne suggests that it may be worth investigating its suitability for assessing bathing water quality.

During the 2020 bathing season, flow cytometry measurements were performed on the same samples used for regular monitoring of bathing water quality. High concentrations of *E. coli* were associated with flow cytometry readings indicating high bacterial loads in the water and the presence of bacteria with large amounts of DNA (Persson, 2020). While these results are promising, the metrics themselves are not perfect indicators of poor bathing water quality. To address this, machine learning is being used to analyse the raw data from flow cytometry, as it contains additional information that could demonstrate whether flow cytometry can serve as a proxy for bathing water quality (Erb et al., 2025).

The 2020 studies relied on manual sampling and laboratory analysis, which were time-consuming and labour-intensive. For real-time monitoring, automatic online flow cytometry presents a more practical alternative. This was explored using a BactoSense flow cytometer (bNovate Technologies), which was evaluated alongside ColiMinder at Pålsjöbaden and Malmö, allowing for a direct comparison of the two methods. Analysis of the data is ongoing at the time of writing this report.

Difficulties

When employing automated online flow cytometry for bathing water monitoring, many of the same challenges encountered with ColiMinder were observed, particularly the need for dedicated infrastructure and personnel.

One additional challenge was the requirement for a relatively constant flow rate, which proved difficult to maintain due to the rapid clogging of filters, sometimes occurring within just a few hours.

Recommendations

Recommendations for Inner Children's Bay

As the ultimate source of *E. coli* in Hammarsbäck remains unidentified, and potential health risks to bathers persist, we recommend that the current bathing prohibition at Inner Children's Bay be extended indefinitely until the source of contamination is located and addressed.

To further investigate the contamination source, online monitoring of *E. coli* concentrations could be employed to track changes over time. This could help determine whether high *E. coli* levels correlate with increased activity at the nearby camping site (e.g., during weekends) or follow rainfall, which might suggest stormwater or runoff as potential contamination sources.

Investigation Details

- Investigation Period: A full bathing season to comprehensively understand water quality dynamics relevant to the public
- Location: One monitoring machine at Inner Children's Bay or at the downstream end of Hammarsbäck

Personnel Required

- Technicians for the installation phase
- Personnel for regular maintenance and monitoring of the machine during the investigation period
- Analysts to interpret the data collected

Infrastructure and Consumables Required

- A ColiMinder device
- An enclosed and protected location to house the machine
- Reliable electricity and internet access
- Consumables for the ColiMinder and supporting water infrastructure (e.g., a water pump and filters)

Knowledge Requirements

- Personnel operating the machine should understand its functionality and the project's objectives
- Analysts should have expertise in statistics and microbial bathing water quality

Additional Recommendations

A detailed investigation into possible contamination sources along Hammarsbäck should also be undertaken. This should include a survey for potential misconnected pipes or sewage leaks. Measures should be implemented to address water stagnation at the location in Hammarsbäck with the poorest water quality.

To evaluate the effectiveness of these interventions, faecal indicator bacteria concentrations should be measured using standard methods both before and after the work is carried out.

Recommendations for Helsingborg

If online monitoring of *E. coli* using ColiMinder is implemented for Helsingborg's beaches, the following recommendations should be considered:

Developing Contingency Plans Prior to Installation

Frequent monitoring is the primary advantage of ColiMinder; therefore, it is crucial to minimise interruptions during operation. A contingency plan should be developed to address common issues encountered during previous trials, such as equipment failures, power outages, or environmental challenges.

Establishing Thresholds for Poor Water Quality

At present, there are no defined thresholds for faecal indicator bacteria in seawater specific to ColiMinder or equivalent to Swedish guidelines for standard methods. Thresholds could be developed by comparing ColiMinder results with those obtained using standard methods from the same seawater samples, including samples representing both good and poor water quality.

Defining Actions When ColiMinder Thresholds Are Exceeded

Protocols should be established for situations where thresholds are exceeded. These might include collecting confirmatory water samples for analysis using standard methods or advising the public to avoid swimming until further results are available.

Selecting Installation Sites

Water quality varies significantly among beaches, so a single monitoring location may not provide a representative overview. While Pålsjöbaden is a convenient site due to its existing infrastructure, water quality at this beach is typically good, limiting the usefulness of ColiMinder at this location. To minimise public health risks, ColiMinder units should be installed at beaches known to experience the poorest water quality.

Additional Recommendations

Other rapid monitoring tools, such as flow cytometry, should also be evaluated for potential implementation. However, research into the suitability of flow cytometry for bathing water monitoring is ongoing.

Rapid methods, including ColiMinder, can only serve as complementary tools and, due to legal requirements, cannot replace standard methods. Standard methods should remain the primary approach for decision-making and public reporting, as they are the only officially approved methods for assessing water quality.

List of Publications and Reports

The following scientific articles, reports, and thesis were produced as part of or in connection with the Urban Swimming project.

Peer-Reviewed Scientific Articles

Erb, I. K., Suarez, C., Frank, E. M., Bengtsson-Palme, J., Lindberg, E., & Paul, C. J. (2024). *Escherichia coli* in urban marine sediments: interpreting virulence, biofilm formation, halotolerance and antibiotic resistance to infer contamination or naturalisation. *FEMS Microbes,* xtae024. https://doi.org/10.1093/femsmc/xtae024

Frank, E. M., Ahlinder, J., Jephson, T., Persson, K. M., Lindberg, E., & Paul, C. J. (2024). Marine sediments are identified as an environmental reservoir for *Escherichia coli*: Comparing signature-based and novel amplicon sequencing approaches for microbial source tracking. *Science of The Total Environment, 907*, 167865. https://doi.org/10.1016/j.scitotenv.2023.167865

Unpublished Reports

Manuscripts in Preparation for Submission to Peer-Reviewed Scientific Journals:

Erb, I. K., Gador, N., Lindberg, E., & Paul, C. J. (2024). *Can flow cytometry be used in bathing water monitoring? Investigations with online instruments and machine learning*. [Manuscript in preparation]. Lund University.

Frank, E. M., Suarez, C., Erb, I. K., Jephson, T., Lindberg, E., & Paul, C. J. (2024). *Microbial contamination in urban marine sediments: source identification using microbial community analysis and faecal indicator bacteria*. [Manuscript in preparation]. Lund University.

Frank, E. M., Suarez, C., Erb, I. K., Jephson, T., Lindberg, E., & Paul, C. J. (2025). *Assessing bathing water quality with 16S rRNA gene sequencing and viable E. coli quantification*. [Manuscript in preparation]. Lund University.

Theses and Reports

Dwita, A. (2023). *Investigation of faecal contamination in the Hammar's stream in Malmö, Barnviken*. [Internship Report]. Berliner Hochschule für Technik.

Dwita, A. (2024). *Investigating the Source(s) of Microbial Bathing Water Contamination in Marine Environments Using Antibiotic Resistance*. [Bachelor's Thesis]. Berliner Hochschule für Technik.

Erb, I. K. (2022a). *Characterisation of Escherichia strains isolated from marine sediments: Investigating taxonomy, virulence, antibiotic resistance, and survival mechanisms*. [Master's Thesis]. Lund University.

Erb, I. K. (2022b). *Sampling during the Summer of 2022: Online Monitoring of Seawater in Helsingborg, Manual Sampling in Malmö, Barnviken*. Sweden Water Research.

Gudmundsson, S. (2024). *Hydrodynamic modelling of E. coli along the urban coast of Helsingborg*. [Master's Thesis]. Uppsala University.

Gullberg, E. (2024). *Weather factors and E. coli concentration in Barnviken, Malmö: A Linear Mixed Model Approach*. [Bachelor's Thesis]. Lund University.

Persson, M. (2020). *Evaluating the use of flow cytometry for routine monitoring of bathing water quality*. [Master's Thesis]. Lund University.

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Boehm, A. B. (2007). Enterococci concentrations in diverse coastal environments exhibit extreme variability. *Environmental Science & Technology, 41*(24), 8227–8232. https://doi.org/10.1021/es071807v

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Acknowledgements

The authors of this report would like to express their gratitude to the following individuals and organisations for their invaluable contributions to the Urban Swimming project:

The crew of Sabella and Tage Rosenqvist for their assistance with sampling.

The city of Helsingborg and the city of Malmö for their support in facilitating fieldwork and equipment installation.

Mekano AB, Amanda Widén (NSVA), Petra Larsson, Markus Fröjd (VA SYD), and Ludvig Andersson (KZ Handels) for their help in setting up and maintaining the ColiMinder and BactoSense systems.

All researchers and students who participated in data collection, analysis, and reporting throughout the project.

Your contributions have been critical to the success of this project and have significantly advanced our understanding of bathing water quality.