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Skov, L. S.; Chhetri, Ravi Kumar; Vezzaro, Luca

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ICUD-0443 How much can we trust data from the real world? Assessing the performance of online sensors for CSO monitoring when operated in non-ideal conditions

L. S. Skov[1], R. K. Chhetri[1] and L. Vezzaro[3]

1 *Department of Environmental Engineering (DTU Environment), Technical University of Denmark, Bygningstorvet, 2800 Kongens Lyngby, Denmark*

Summary

Online water quality sensors are often proposed as a tool to monitor/control integrated urban drainage systems. However, their high maintenance requirements limit their application. This study aimed at quantifying the accuracy of water quality sensors when they were not properly maintained. Ammonia and turbidity sensors were placed at a CSO structure in Virum (Denmark). Sensors accuracy was compared against grab samples collected on a daily basis, to assess the degradation of sensor performance in time. The preliminary results show how, despite the challenging setup, sensors provided good quality measurements, supporting a wider application of online sensors in urban drainage systems.

Keywords

uncertainty;water quality;data validation;combined sewer overflows;sensor drift

Introduction

Online water quality sensors are increasingly emerging as a tool to monitor water quality in integrated urban drainage/wastewater systems and allow better control strategies of these systems (Campisano et al., 2013). The available sensors allow the measurement of a range of water quality parameters, such as temperature, pH, turbidity, suspended solids, organic carbon, chemical oxygen demand, conductivity, ammonia, nitrate and total nitrogen (Campisano et al., 2013). Compared to traditional monitoring approaches, based on automatic samplers, online sensors provide several advantages, due to the high temporal resolution of the collected measurements. Online sensor can in fact (a) provide a better understanding of water quality processes taking place in sewer systems (see e.g. the analysis performed by Métadier and Bertrand-Krajewski, 2012); (b) quantify pollutant emissions from combined sewer overflow (CSO) and their impacts on the receiving waterbody (e.g. Boënne et al., 2014; Brzezińska et al., 2016); (c) deliver data for water-quality based real time control (e.g. Fricke et al., 2016; Hoppe et al., 2011) strategies.

Based on the available literature, the majority of the existing application of water quality sensors is limited to research activities, with few important exceptions of full scale monitoring and control (e.g. Fricke et al., 2016; Langeveld et al., 2013). Compared to wastewater treatment plants (WWTPs), where online sensors are widely applied (e.g. Olsson et al., 2014), sewer systems are characterized by a harsh environment, which require a constant maintenance effort. For example, the Standard Operating Procedure (SOP) for sensor maintenance proposed by Alferes et al. (2014) suggests a sensor maintenance frequency of one/two weeks. Such high maintenance requirements, together with the fact that sensors are scattered across urban areas (instead of being in a single location, as for WWTPs), might discourage water utilities from installing and operating these online sensors, or can lead to deficient sensor maintenance (e.g. with a lower frequency than what is suggested in existing SOP).

This study aimed at quantifying the uncertainty of an online water quality sensor when operated in non-ideal conditions (i.e. when the SOP is not applied correctly). Two online sensors (measuring ammonia and turbidity) were placed at a combined overflow structure (CSO), measuring directly in the wastewater flow (e.g. *in situ* configuration). The main assumption behind this study is that quantifying the temporal decrease in the sensor accuracy can help to extract useful information from otherwise poor quality measurements. This can eventually lead to methodology allowing more relaxed maintenance requirements, encouraging a wider application of online sensors across urban drainage systems.

Material and Methods

Monitoring site

The online sensors were place at a CSO structure located at Ålebækken (Virum, Danmark). The upstream catchment is a 1015 ha residential catchment, with an estimated population equivalent of 45,000 inhabitants. The CSO is located close to a dismissed WWTP plant, with an open sewer channel connected to the overflow weir (Fig. 1). This rare infrastructure allows easy access to the site, where sensor maintenance requires minor efforts compared to typical underground locations.

An ion-selective sensor (HACH AN-ISE) and an optical turbidity sensor (HACH SOLITAX) were installed at the CSO structure. The AN-ISE sensor measures four different water quality parameters, but only ammonia was considered in this study.

Fig. 1. *Left: In-situ sensor installation (blue arrow indicates the flow direction). Left: configuration of the AN-NISE and Solitax Hach sensors (right).*

Sensors were placed "in-situ" i.e. directly in the wastewater flow, with a "low-budget" installation: sensors were installed on a wooden frame and no compressed air cleaning was installed (only a small plastic screen was installed to avoid accumulation of large debris on the sensors). This challenging setup was explicitly design to mimic a non-optimal installation, where resources are limited or there are logistical issues (e.g. lack of space for air compressor) compared to installations at WWTP. Sensors data were collected at 1-min resolution. Collected data were validated by using the quality tests included in the EVOHE data validation software (Bertrand-Krajewski, 2013).

Evaluation of sensor accuracy

The monitoring campaign lasted for about 3 months (December 2016 – early March 2017). . Grab samples were collected on daily basis (Monday to Friday) and analysed in the laboratory. The sensor accuracy was calculated by comparing the laboratory measurements against the sensor readings (filtered on a 5-min average in order to reduce the effect of noise).

The dynamic behaviour of sensors performance was assessed by subdividing the monitoring campaign in three phases:

- Phase A – Best Achievable Accuracy (3 weeks). In this phase sensors were maintained and cleaned on a daily basis in order to establish a baseline on the sensor performance;
- Phase B – Standard Operating Procedure (3 weeks). In this phase the SOP proposed by Alferes et al. (2014) to obtain good quality measurements was followed. This SOP required a weekly maintenance of the sensors.
- Phase C – Non Ideal Conditions (8 weeks). In this phase we simulated a poor maintenance scenario, where sensors maintenance was performed only on a biweekly basis.

For Phase B and C it is possible to build accuracy curves, i.e. it is possible to observe the sensors performance as function of time since the last maintenance operation

Results and Discussion

Collected data

Examples of the collected ammonia measurements are shown in Fig. 2 and Fig. 3. Data gaps were caused by memory problems with the sensor controller, resulting in a loss of data during weekends. However, this did not affect the accuracy estimation, since grab samples were only during weekdays.

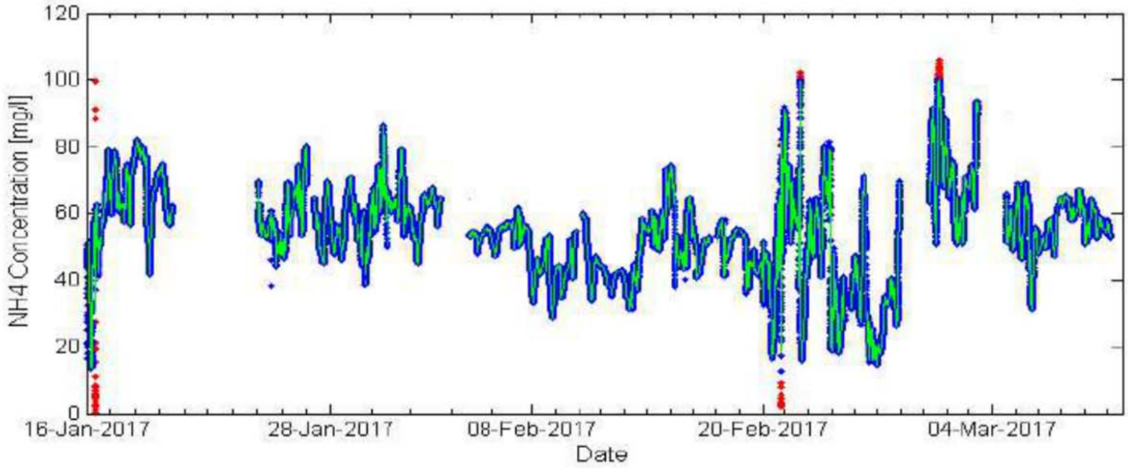

Fig. 2. *Ammonia measurements collected during Phase B. Red data have been discarded as outliers by the data validation. The green line shows the 5-minute average.*

Fig. 3. *Example of ammonia measurements form AN-ISE sensor and grab samples collected during phase B. The vertical line show when sensor maintenance was performed.*

Phase A – Best Achievable Accuracy

The comparison between the lab measurements and the sensor data for NH4 is shown in Fig. 4. The results show that the deviation between the two type of measurement lies below 20% for the majority of the data. The median deviation between the AN-ISE sensor and the grab samples was 5. mg/l. When considering the uncertainty linked to the grab sampling and the laboratory measurements, the AN-ISE sensor showed a good accuracy.

Phase B – Standard Operating Procedure

Fig. 5 shows the percentage deviation between the sensor measurements and the laboratory measurements as a function of time since sensor maintenance. After one week since the sensor maintenance the divergence between the measurements remained within acceptable ranges (2-42 %) for the majority of the cases.

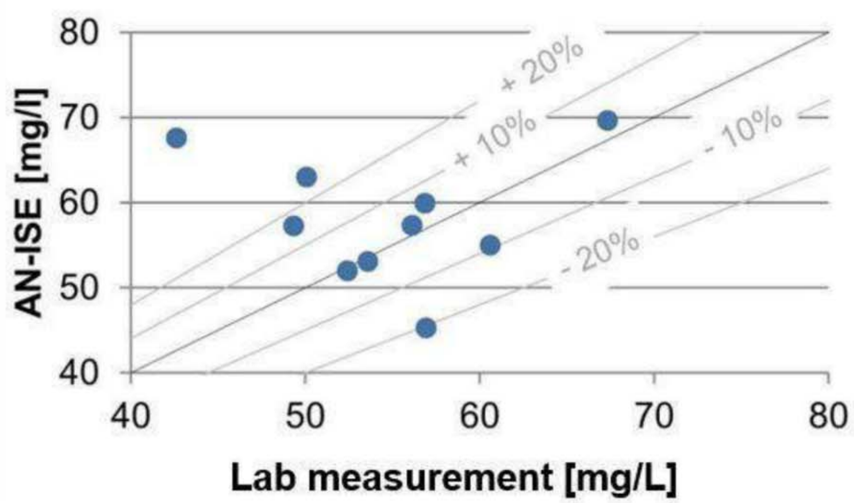

Fig. 4. *Comparison between laboratory (autoanalyzer) and online sensor measurements (5-min average) of NH4 concentrations (Phase A).*

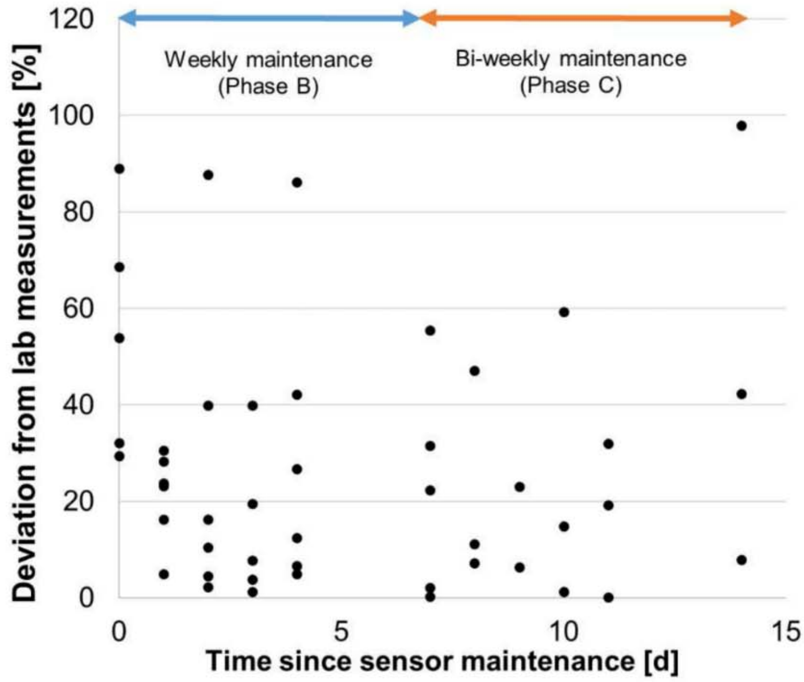

Fig. 5. *Deviation between laboratory and online measurements (5-min average) for NH4 concentration as function of time since sensor maintenance (Phase B and C).*

The median deviation between the AN-ISE sensor and lab data for the measurements is 20.4 %. Considering that typical measurement errors in traditional sewer quality monitoring lies in the 30% range (e.g. Bertrand-Krajewski and Bardin, 2002), the results confirm that the SOP proposed by Alferes et al. (2014) ensures good quality measurements.

Phase C –Non Ideal Conditions

When sensors were not maintained properly, the divergence between measurements remained in a similar range as in Phase B (Fig. 5). The median deviation during the second week since maintenance was 22.7% with an apparent increase throughout time. However, no significant trends were identified based on the available data. Based on these preliminary results, it can be suggested that the SOP described in Alferes et al. (2014) might be relaxed (i.e. the maintenance frequency can be decreased) without leading to an important decrease in the sensor performance.

Future outlook

The presented results present a preliminary assessment of online sensors performance through time. The accuracy estimations can be improved by increasing the number of laboratory measurements through the installation of an autosampler. This will reduce the uncertainty linked to collection of grab samples and will increase the number of available measurements, creating a larger data background for the identification of possible temporal trends in the sensor performance. Also, longer interval between sensor maintenance (3-4 weeks or longer) can be tested to better quantify the effect of poor maintenance. Turbidity measurements showed high variability and they are not shown in this analysis since they require a process of data filtering before an accuracy analysis can be performed.

Overall, the preliminary results suggest that the maintenance requirements, now defined in SOP mainly developed for research purpose, might be relaxed without leading to important loss of information. This would decrease the sensor maintenance costs and thereby encourage more water utilities to invest in such technologies. Also, sensor purpose should be taken into account when defining the level of "acceptable accuracy": if the sensors are utilized for water-quality RTC (as in the example presented by Fricke et al., 2016) a lower accuracy can be allowed. In fact, sensors only need to detect changes in the pollutant concentrations during rain events (e.g. from "highly polluted" to "highly diluted" wastewater). Conversely, if sensors are used to quantify CSO loads for reporting purpose (as e.g. required by the French environmental legislation - Arrêté du 21 juillet 2015), high sensor accuracy should be ensured.

A more thorough evaluation of sensor performance (as in Villez et al., 2017) can eventually lead to the estimation of typical "error curves", which would allow an online correction of the measured data. These error curves can also be employed in uncertainty-based calibration of water quality methods (using e.g the approach proposed in Vezzaro et al., 2013) or to quantify the error in CSO load estimations (as in Bertrand-Krajewski and Bardin, 2002).

Conclusions

The presented study investigated the temporal development of accuracy of online water quality sensors for monitoring sewer water quality. By comparing the measurements provided by sensors, which were operated in non-ideal conditions, against laboratory measurements, it is possible to conclude that:

- The sensor provided good quality data despite the challenging installation setup
- Existing Standard Operating Procedures (SOP) ensure an acceptable quality of the collected water quality data (with a median deviation of about 20%)
- A relaxation in the maintenance requirements (from a weekly to a biweekly sensor cleaning) did not lead to important decrease in the sensor performance.

The presented results can lead to a better quantification of sensor performance throughout time. This would support the development of new tools to extract information from otherwise poor quality data and thereby, supporting a wider application of online water quality sensors in sewer systems.

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