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Low-cost sensors in monitoring Water Sensitive Urban Design (WSUD) performance in Singapore

— Lab testing of water level sensors



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Introduction

The ABC Waters Programme, with its design based on Water Sensitive Urban Design (WSUD), has successfully implemented stormwater control systems across Singapore for 15 years. Yet, there is relatively little attention paid to monitoring ABC Waters features' medium to long-term performance. The relatively limited monitoring efforts restrict the ability of public agencies and private developers to provide adequate maintenance for existing systems and to optimize the design of new systems.

Compared with traditional monitoring equipment, low-cost sensors present economic advantages and flexibility for operation and communication, also, by allowing a large decentralized spatial monitoring, have a great potential in environmental monitoring.

In this study, we aim to explore the potential of the low-cost sensor in monitoring work via testing its performance compared to the traditional sensor. And here presents the lab testing experiment for water level sensors.

Methodology

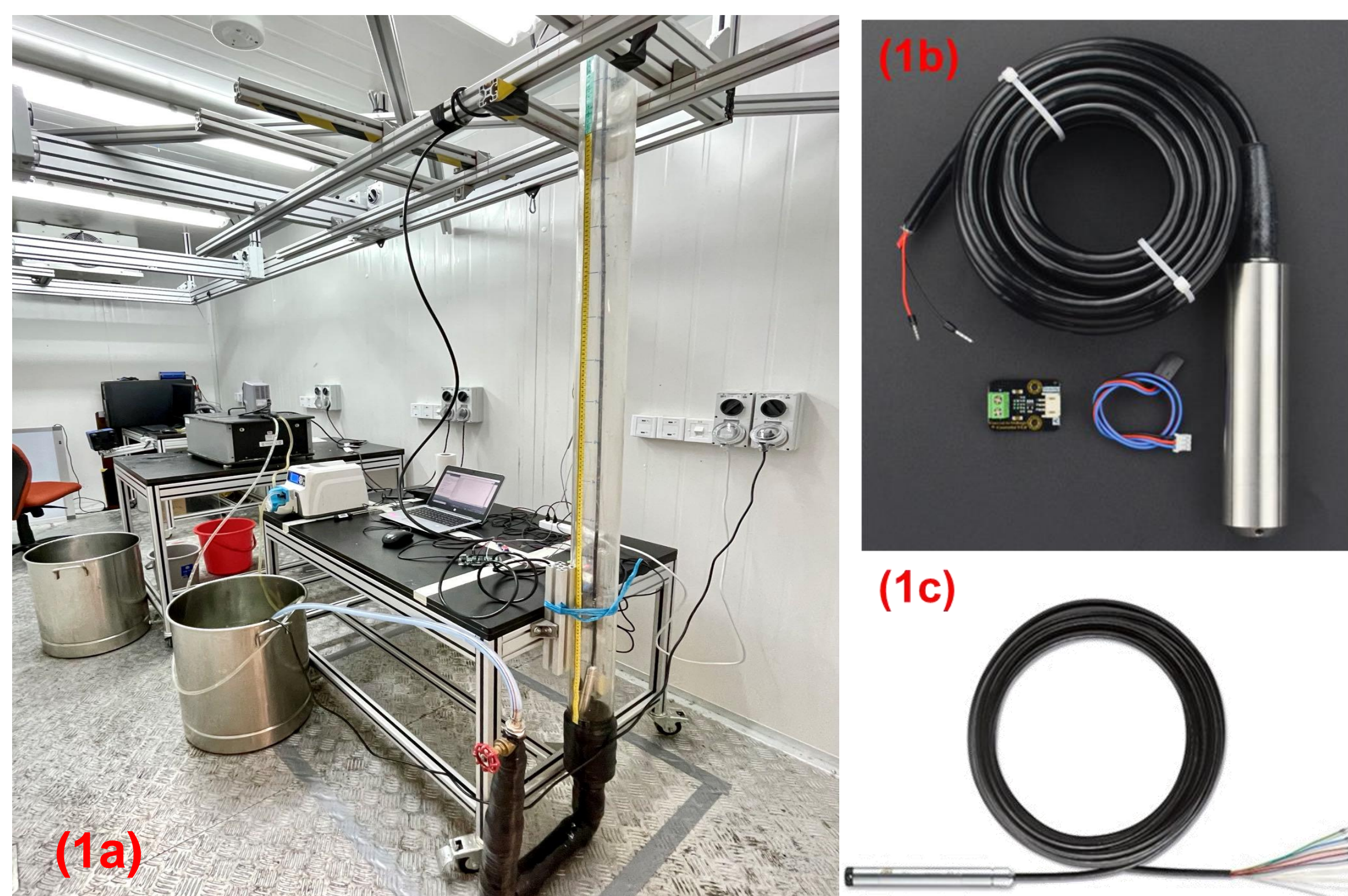


Figure 1. Setup of water level sensors testing experiment (1a), low-cost sensor KIT0139 (1b), traditional sensor OTT PLS (1c). Both sensors are pressure Transducers.

- I. The lab experimental platform of testing the water level sensors includes:
 - Water column (height ~2m)
 - Low-cost water level sensor KIT0139
 - Traditional water level sensor OTT PLS
 - Arduino Mega2560 (microcontroller)
 - Laptop with Arduino IDE (online control platform)
 - PolyScience Heated Circulators (controlling water temperature)
 - Water pumps & water tanks
- II. Three testing cycles at each water temperature degree were run:
 - Temperature degrees: 25°C, 30°C, 35°C
 - Each cycle includes two processes:
 - a) water goes up (0~170cm by increments of 10cm)
 - b) water goes down (170~0cm by decrements of 10cm)
- III. 20 water level measurements each from KIT0139 and OTT PLS at each water level were recorded.
- IV. The reference water level was measured visually with a graduated ruler (1 mm marks).
- V. The main parameters used to assess the low-cost sensor:
 - Accuracy
 - Precision
 - Sensitivity to water temperature

Results & Discussion

• Water level measurements of KIT0139 and OTT PLS

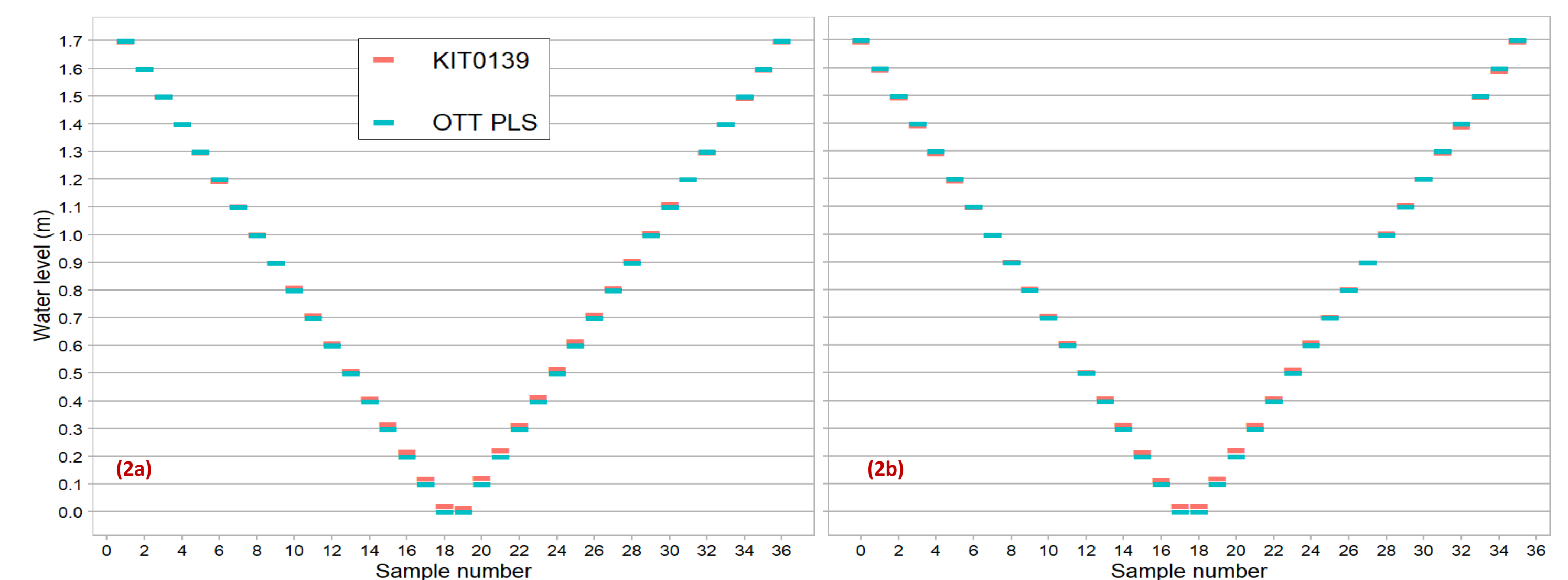


Figure 2. Water level measurements (mean value) of KIT0139 and OTT PLS over a range of reference water levels. (2a) at 25 °C; (2b) at 30 °C; (2c) at 35 °C.

- ◆ Traditional sensor (OTT PLS) showed reliability and stability over the measuring range at three water temperatures.
- ◆ Low-cost sensor (KIT0139) showed visible drift in measuring water levels, especially $\leq 0.7\text{m}$.
- ◆ Deviation of measurements by Low-cost sensor (KIT0139) increased with the raising of water temperature.
- ◆ Relatively little impact of water flow directions on measurements (mean value) by low-cost sensor (KIT0139).

• Accuracy and precision of the low-cost sensor KIT0139

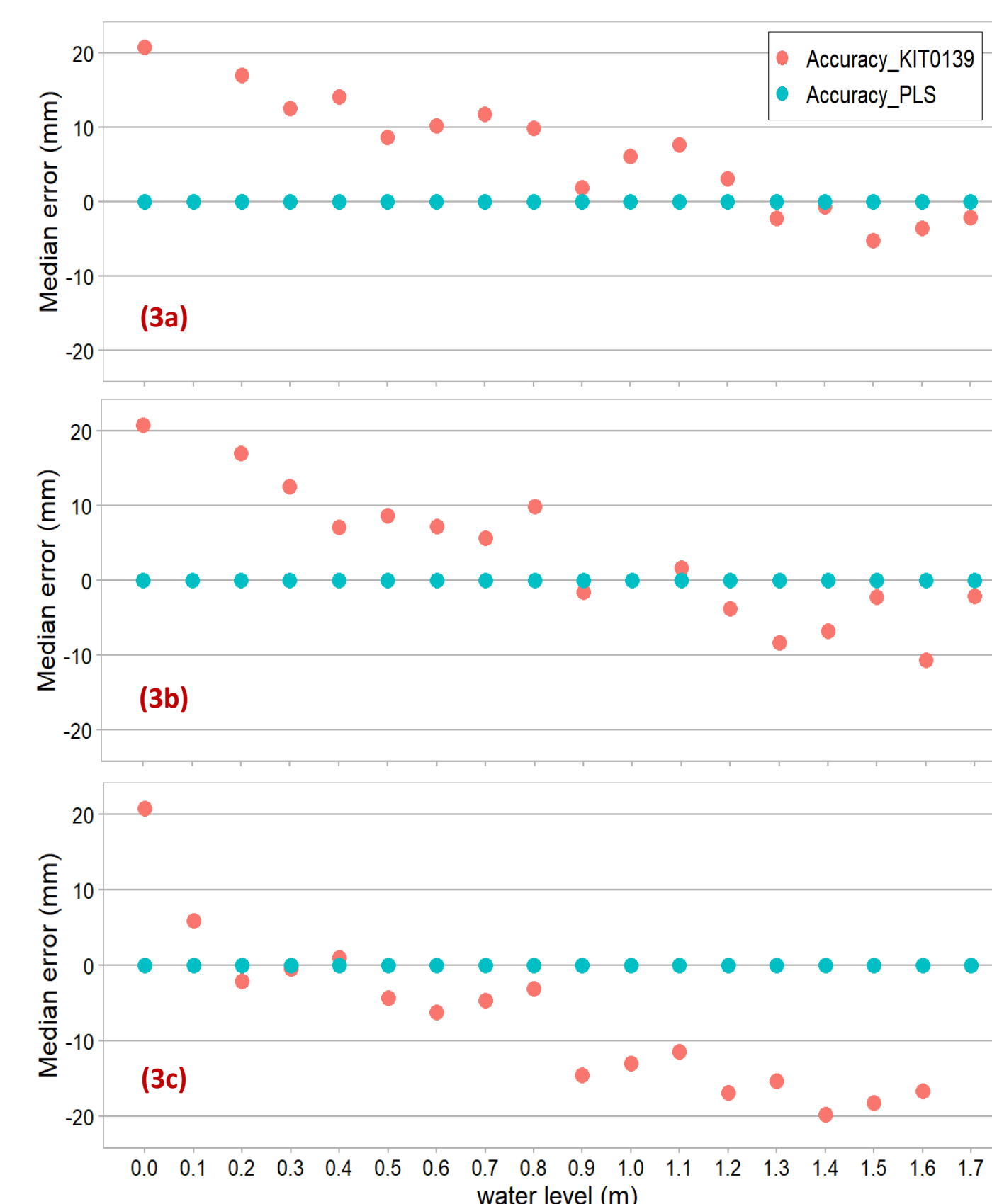


Figure 3. Accuracy of KIT0139 and OTT PLS based on 2160 measurements from each sensor at each water temperature. (3a): at 25 °C; (3b): at 30 °C; (3c): at 35 °C. Each point represents the average of 40 measurements at a given level.

- ◆ Accuracy of traditional sensor (OTT PLS): $< \pm 0.5\text{mm}$.
- ◆ Accuracy of low-cost sensor (KIT0139): $< \pm 22\text{mm}$.

• Calibration of the systematic error

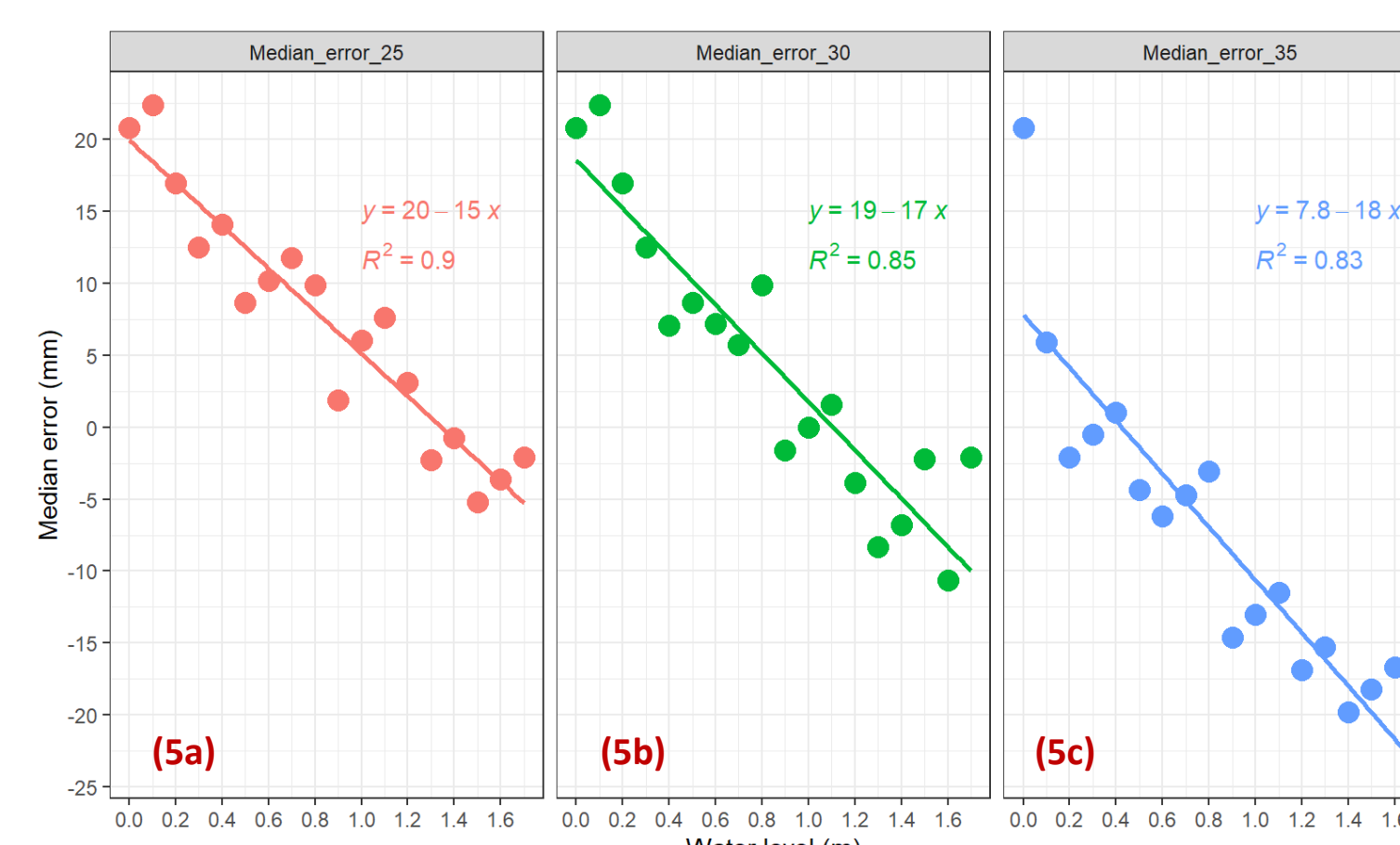


Figure 5. Relationship between median errors of measurements by Low-cost sensor (KIT0139) and reference water levels at each water temperature. (5a): at 25 °C; (5b): at 30 °C; (5c): at 35 °C.

- ◆ P-values (< 0.001) indicated a statistically significant (**).
- ◆ Accuracy after correction: $< \pm 5\text{mm}$ at 25 °C
 $< \pm 8\text{mm}$ at 30 °C
 $< \pm 15\text{mm}$ at 35 °C

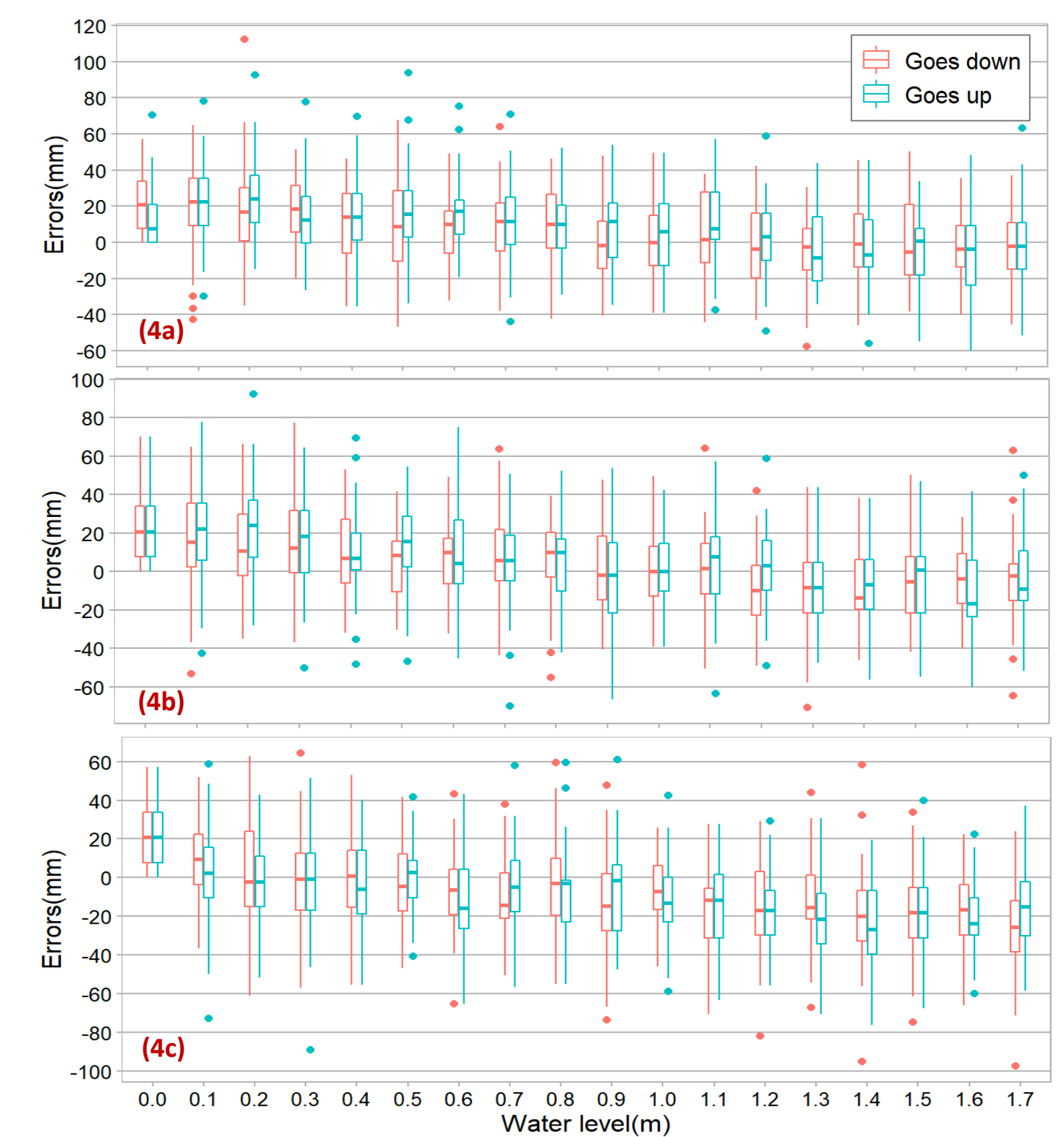


Figure 4. Error boxplot shows the variability of KIT0139 in water goes up and water goes down processes based on 2160 measurements at each water temperature. (4a): at 25 °C; (4b): at 30 °C; (4c): at 35 °C.

- ◆ Precision of low-cost sensor (KIT0139) was the same at three water temperatures: $< 40\text{mm}$.
- ◆ Variation of water flow directions led to the change of precision of low-cost sensor (KIT0139).

• Sensitivity to water temperature

Water temperature	25°C	30°C	35°C			
Parameters	Accuracy	Precision	Accuracy	Precision	Accuracy	Precision
KIT0139	$< \pm 5$	< 40	$< \pm 8$	< 40	$< \pm 15$	< 40
OTT PLS	± 0	no variance	$< \pm 0.5$	< 2	$< \pm 0.5$	< 2

- ◆ Accuracy of low-cost sensor (KIT0139) changed under the variation of water temperatures, while the precision didn't change.
- ◆ Traditional sensor (OTT PLS) kept a high level of accuracy and precision (high reliability).
- ◆ The low-cost sensor (KIT0139) was more sensitive to water temperature variation.

Conclusions

We conducted the lab experiment for assessing the performance of low-cost sensor KIT0139 compared to the traditional sensor OTT PLS. Results revealed that 1) Low-cost sensor KIT0139 has a good accuracy ($< \pm 15\text{mm}$ up to 1.7m at the water temperature range of 25°C~35°C) for the field application (expected accuracy is around $\pm 20\text{mm}$); 2) With the acceptable accuracy and significant economic advantages (the price of KIT0139 is 20 times less than OTT PLS), low-cost sensor KIT0139 is worth for further test in the field and used in WSUD monitoring. 3) Traditional sensor OTT PLS is recommended to be used as the reference sensor for the further testing of low-cost sensors in the field.