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Water Sensitive Urban Design (WSUD) monitoring with low-cost water level sensor in the Tropics

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Highlights

- We tested a low-cost water level sensor compared to a traditional sensor in the laboratory, and the results showed a great potential for the low-cost sensor to be used in field monitoring practices.
- Three months field observations showed that the low-cost sensor functioned as expected and was able to effectively monitor the water level variation for the WSUD system monitored.
- The performance of the WSUD system in terms of stormwater retention will be evaluated based on PCSWMM model that will be calibrated with the empirical data collected from the low-cost sensor monitoring system.

Introduction

To further understand the role of Water Sensitive Urban Design (WSUD) in Sustainable Urban Water Management, the effectiveness of WSUD systems has been extensively studied at watershed and sub-watershed scales (Bellezoni et al., 2021; Gunnell et al., 2019; Yau et al., 2017). However, such studies often ignore the field performance of WSUD systems at the site scale, lacking sufficient empirical data from field monitoring for the model validation and calibration (Hamel et al., 2021; Yin et al., 2021). The absence of field monitoring of WSUD systems is mainly due to the constrained budgets, especially in the developing areas such as Global South and most countries in Southeast Asia (Hamel & Tan, 2021). Since traditional monitoring systems can be costly and time-consuming, relatively few attempts were made for monitoring the medium to long-term performance of WSUD systems in the Tropics (Bertrand-Krajewski, 2021; Hamel & Tan, 2021). The limited monitoring efforts restrict the ability of public agencies and private developers to provide adequate maintenance for existing WSUD systems and to optimize the design of new systems (Kuller et al., 2019).

Compared to traditional monitoring equipment, low-cost sensors present great economic advantages by providing useful data at a considerably lower expense. Also, low-cost sensors often work on open-source platforms (e.g., Arduino), hence they are more flexible in operation and communication (Cherqui et al., 2020). Given their flexibility, low-cost sensor technology has been emerging in many fields and shows reliable results, including for air quality assessment (Ali et al., 2016; Morawska et al., 2018), air temperature measurement (Sun et al., 2019), water quality monitoring (Lambrou et al., 2014; Murphy et al., 2015), and agriculture (Valente et al., 2020). In this study, we aim to explore the potential of low-cost sensor in supporting the affordable and flexible monitoring network for WSUD systems, that can be promoted throughout the region for medium to long-term monitoring. Following extensive laboratory testing of the sensors (Ding et al., in prep), the main objectives of this study are to: 1) Assess the performance of the LCS monitoring system with comparison to the traditional sensor in the field, and 2) Evaluating the performance of a WSUD system based on the empirical data collected from the low-cost sensor monitoring system.

Case study

The WSUD system monitored in this study is a Rain Garden which located near the NIE art gallery on NTU campus in Singapore. With the collaborative effort between PUB, AECOM, Greenerth Consultants Pte Ltd., and NIE (National Institute of Education), this Rain Garden has been officially launched in 2017. It is a conventional rain garden system that comprises four layers: 1) plants and pond area, 2) filter layer (loamy sand), 3) transition layer (coarse, washed sand), and 4) drainage layer (coarse gravel and perforated sub-soil pipes). The cross-section scheme is shown in Figure 1(a). The main catchment area and the theoretical water flow for this Rain Garden are shown in Figure 1(b) and 1(c). This Rain Garden was designed to capture for 3-

month storm volume, and there is an overflow sump to prevent the Rain Garden from overflowing during intense storm events. The Excess runoff is conveyed directly to the nearby drain.



Figure 1. (a) shows the cross-section of the Rain Garden monitored by the low-cost sensor monitoring system; (b) and (c) shows the main catchment area and the theoretical water flow for this Rain Garden (Credit: Kim Irvine, AECOM).

Methodology

Field implementation of low-cost water level sensor monitoring system

Among the water level sensor technologies, the submersible pressure transducer and ultrasonic sensor are the most used because of their good accuracy and flexibility (Zhu et al., 2023). Considering the field application, ultrasonic sensors are easy to be disturbed by the factors such as air temperature, wind, and rainfall (Ouychai, 2015; Zhang et al., 2019). Thus, the submersible pressure transducer with the anti-corrosion surface matches better with our requirements. Two water level sensors including a low-cost sensor (KIT0139 model from DFRobot) and a traditional sensor (OTT PLS model from OTT HydroMet) were selected for the lab testing and assessment (Ding et al., in prep) before being implemented in the field.

After the laboratory assessment, two low-cost water level sensor monitoring stations have been installed in the Rain Garden described in Case Study section, as shown in Figure 2. The station 1 monitoring system was installed in the outlet sump in this Rain Garden in June 2023, comprising a low-cost water level sensor (KIT0139), a traditional water level sensor (OTT PLS), a low-cost temperature sensor (DS18B20), a designed PCB board (inside a waterproof enclosure) (Figure 3 (a)) for all the electronic connections. Station 2 was installed in the overflow sump in this Rain Garden in November 2023, and consists of three low-cost water level sensors (KIT0139), a low-cost temperature sensor (DS18B20), and a designed PCB (Figure 3(b)). For both stations, 10 measurements by the low-cost sensor and 1 measurement by the traditional sensor were recorded every 5 minutes, and the data was saved in the SD card and transferred to the online Google sheet in real-time via WIFI and a Lilygo module (Figure 3(c)).



Figure 2. Field implementation of the water level monitoring station 1 and 2 in a Rain Garden in Singapore.

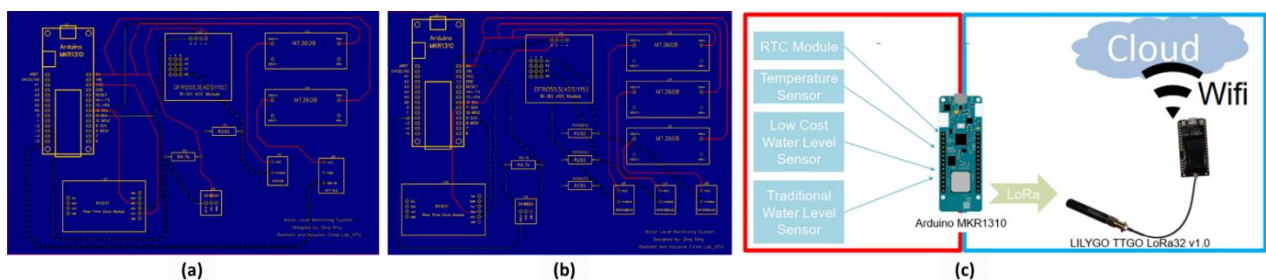


Figure 3. Electrical schematic design for station1 (a) and station 2 (b). The real-time data transmission from the stations to online Google sheet is shown in (c).

Assessing the performance of the low-cost water level monitoring system in the field

By applying two low-cost water level monitoring stations, we will firstly use the data from station 1 to assess and compare the performance of the low-cost water level sensor and the traditional sensor in the field. Then the performance and calibration of the low-cost sensors in the field compared to the laboratory testing will be done based on data collected from the station 2.

Evaluating the performance of the WSUD system (Rain Garden) monitored

With the information from the low-cost water level monitoring system in the Rain Garden. The performance of this Rain Garden in terms of stormwater retention under different rainfall events will be evaluated based on PCSWMM model. The empirical data collected from the low-cost water level monitoring stations will be used to calibrate the PCSWMM model for more precisely calculation of the water balance changes. Different climate scenarios will also be applied for the evaluation of this Rain Garden.

Results and discussion

Field observations for the low-cost water level monitoring system

Three months of observations (July 2023 – October 2023) of the performance of the water level monitoring system station 1 in the field showed that the water level measurements by the low-cost sensor (KIT0139) were quite consistent with the measurements by the traditional sensor (OTT PLS) (see selected rainfall events in Figure 4 (a)). While the low-cost sensor showed a relatively higher errors rate at 0~5cm water level compared to the errors within [-10, 10] mm observed from the other levels of the testing range of 0~1.7m in the lab experiments (Ding et al., in prep), there was no observed drift for the field implementation. During the first three-month observations, most of the errors of the measurements by the low-cost sensor in the field setup were within the range of [-10, 10] mm (Figure 4 (b)). Indicating that compared to the traditional sensor, the low-cost sensor functioned as expected and was able to effectively monitor the water level variation for the Rain Garden.

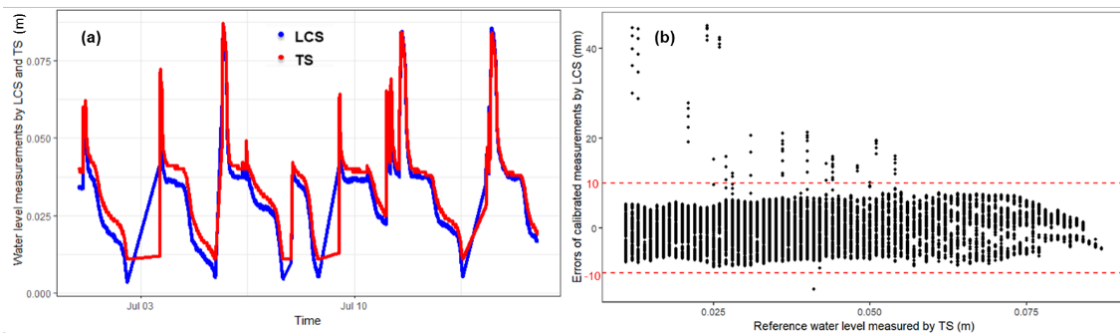


Figure 4. (a) shows a few selected rainfall events during 1st July and 15th July 2023, showing that the measurements by the low-cost sensor are quite consistent with the measurements by the traditional sensor. (b) shows the errors between the calibrated measurements by the low-cost sensor and traditional sensor are mostly within the range of [-10, 10] mm.

Performance assessment for the Rain Garden monitored by the low-cost water level monitoring system

To evaluate the performance of the Rain Garden for stormwater retention at its neighbouring catchment area, a preliminary PCSWMM model was setup for this Rain Garden (Figure 5). This model comprising one sub catchment, two junctions, one main outfall, and the Rain Garden as a LID control feature placed in this sub catchment area. As the input parameters will need to be calibrated with the empirical data collected from the low-cost water level monitoring system, the complete evaluation results will be shown during the conference in June 2024.

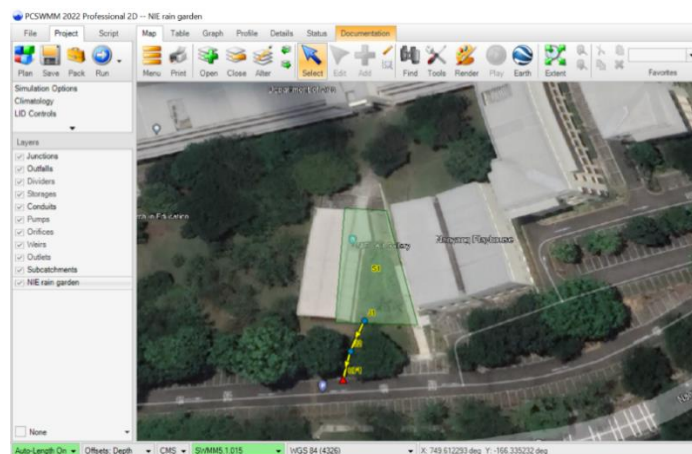


Figure 5. The PCSWMM setup for evaluating the performance of the Rain Garden monitored.

Conclusions and future work

To explore the potential of low-cost sensors in WSUD monitoring, we implemented a low-cost water level sensor (KIT0139) in a Rain Garden in Singapore and compared it with a traditional sensor (OTT PLS). Three months field observations showed that the LCS functioned as expected and was able to monitor water level variation for the Rain Garden, confirming previous lab experiments (Ding et al., in prep). Therefore, with sufficient accuracy and precision, as well as significant economic advantages compared to the traditional water level sensor (the price of the traditional sensor (OTT PLS) tested is about 20 times more than the LCS (KIT0139)), the low-cost sensor KIT0139 has potential to be used in WSUD system monitoring. Performance evaluation of the Rain Garden monitored via PCSWMM model calibrated with the data collected from the low-cost sensor monitoring system will be done soon, the results on how low-cost sensor monitoring system could contribute to the monitoring and modelling for the WSUD features will be shown in the conference in June 2024.

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