Soil moisture distribution analysis of subsurface flow constructed wetland using capacitive soil moisture sensor and its relation with *Ipomoea reptans* Poir growth

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Abstract. Subsurface Flow Constructed Wetland (SFCW) is commonly used as secondary treatment for septic tank with vegetation on it as biofilter, this made water stream out from the installation more environmentally friendly. This research aimed to study the distribution of soil moisture and its correlation to water spinach (*Ipomoea reptans* Poir.) growth in SFCW using Capacitive Soil Moisture Sensor (CSMS). This research was done by monitoring soil moisture and water spinach growth parameters at the sand layer of SFCW in Smirantani Village, Piyungan District, Bantul Regency, Special Region of Yogyakarta. This SFCW is connected with waste treatment system to collect wastewater from a house with three family members. Soil moisture monitoring was conducted using CSMS which installed on four different areas using two different depths variation (0.1 and 0.2 m) in 6 m² of the SFCW. *Ipomoea reptans* Poir growth parameters was monitored in the stem length. The result proves that soil moisture content at distance of 0.25 m from the outlet pipe position was higher than soil moisture obtained at 0.75 m. Moreover higher soil moisture content has positive correlation with stem length of *Ipomoea reptans* Poir.

1. Introduction

One of the most critical sanitation problems in Indonesia is the contamination of groundwater. It causing well water pollution which mainly source from septic tank system. This water pollution is often occurring in rural areas which located in small-town areas. The pollution occur due to the infiltration of wastewater into shallow groundwater sources [1]. This is evidenced by the fact that 50–80% of contamination of groundwater flows is nitrate (NO₃⁻) and phosphate (PO₄³⁻) which generated from domestic wastewater [2].

Subsurface Flow Constructed Wetland is one of most effective technology to prevent contamination of well water [3]. SFCW is different compared to infiltration wells, because SFCW requires excavation that is shallower than infiltration wells [4]. The higher position of SFCW makes domestic wastewater in SFCW further away from groundwater sources compared to infiltration wells. The filtration layer used in SFCW consists of 0.2 m of sand above and 0.6 m of gravel below the sand layer.

Plant growth is the most important factor in wastewater treatment at SFCW. In here, the plants are function as biofilters since they can remove pollutants in household waste [5]. Plants absorb water which contain N (nitrate), and P (phosphate) in domestic wastewater for growing purpose [6]. For that,
the SFCW design must be analyzed for its moisture distribution, due to the ideal SFCW has a well-distributed soil moisture content. It is required that each part of SFCW has to have same soil moisture value at the same time. The analysis of SFCW needs to be done, then the results could be used to determine whether the SFCW design is ideal or not. For that, this study was aimed to observe the distribution of soil moisture in SFCW and the correlation between soil moisture and water spinach (*Impomea reptans* Poir.) growth.

2. Materials and methods

2.1. Soil moisture monitoring device validation

Soil Moisture Monitoring Device (SMMD) is constructed and consist of Capacitive Soil Moisture Sensor (CSMS) SKU: SEN0193, microcontroller Arduino Mega 2560 equipped with DS3231RTC Module, and micro SD Card Adapter as shown in Figure 1. There were ten units of CSMS employed in one unit of SMMD. Laboratory validation was carried out on each unit of CSMS by comparing sensor response value (in the form of frequency, Hz) to the actual soil moisture obtained from thermogravimetric analysis. CSMS validation apparatus is shown in Figure 2. Soil sample obtained from SFCW were saturated using water in cylinder pot for 24 hours before validated. CSMS was buried at the same depth (Figure 2) to record soil moisture change, along with that soil was dried using dry air (40°C and relative humidity 50%) for 4 days (96 hours). Thermogravimetric analysis to determine actual soil moisture was conducted by measuring the weight loss of soil sample during 96 hours of soil drying. By using weight of cylinder pot with wet soil (*W*₁), weight of cylinder pot with dry soil (*W*₂), weight of empty cylinder pot (*W*₃), then the actual soil moisture was calculated using equation (2.1)[7].

\[
\text{Soil Moisture (%db)} = \left( \frac{W_1 - W_2}{W_2 - W_3} \right) \times 100\%
\]  

(2.1)

![Figure 1. Soil moisture monitoring devices: (a) capacitive soil moisture sensor; (b) microcontroller arduino mega 2560; and (c) micro SD card adapter](image-url)
2.2. Experimental setup on subsurface flow constructed wetland

The SFCW location is in Piyungan sub-district, Bantul district, Yogyakarta. The septic tank which is made from watertight material (1550 liter) was connected to SFCW. As shown in Figure 4, one unit of SFCW has 0.2 m depth of sand layer at the top and 0.6 m depth of gravel layer. The sand used in this SFCW have particle size of 0.02-2 mm, meanwhile the gravel has 10-27 mm (Figure 5). There is one horizontal leach pipe (PVC pipe 3 inch) buried in the SFCW which was perforated with 3 mm holes along the pipe at the bottom side, and located on 0.1 m below the bottom of sand layer.

Eight units of CSMS were installed on SFCW in four different areas (A, B, C, and D) as shown in Figure 3. Each area has 0.5 m\(^2\) space with 2 units of CSMS installed at 0.1 m and 0.2 m depth. One
unit of garden as control was used with conventional cultivation method and located near SFCW. Control has 2 units of CSMS installed with the same depth. Latosol soil (Figure 5) was used in control garden without having any blackwater or greywater irrigation. Four water spinach (*Ipomoea reptans* Poir.) were planted in the center of each SFCW area and control garden.

![Figure 5. Sand (a), gravel (b), and latosol soil sample (c)](image)

### 2.3. Data measurement

The soil moisture of SFCW and control garden were monitored during 8 days span. Water spinach (*Ipomoea reptans* Poir) were planted on both SFCW and control for stem length observation as plant growth indicator.

### 2.4. Data analysis

Soil moisture data obtained from SMMD validation phase were calculated to obtain exponential trendline equation [7]. The trendline equation then used as reference to measure the distribution of soil moisture in SFCW in both vertical and horizontal direction. Moreover, soil moisture data then calculated for its correlation with the plant growth.

### 3. Results and discussion

#### 3.1. Soil moisture sensor validation

All units of CSMS were validated using R-square ($R^2$), as shows in **Table 1**, with range from 0.6354 to 0.9809.

| Sensor Code | Trendline Equation | $R^2$ |
|-------------|--------------------|-------|
| A1          | $y = 392.92e^{-0.014x}$ | 0.6520 |
| A2          | $y = 221.15e^{-0.012x}$ | 0.6867 |
| B1          | $y = 575.17e^{-0.015x}$ | 0.6354 |
| B2          | $y = 654.45e^{-0.016x}$ | 0.6547 |
| C1          | $y = 69,253.00e^{-0.036x}$ | 0.9809 |
| C2          | $y = 77,381.00e^{-0.036x}$ | 0.7728 |
| D1          | $y = 1,841.10e^{-0.021x}$ | 0.8063 |
| D2          | $y = 6,644.50e^{-0.026x}$ | 0.8413 |
| Control 1   | $y = 526.02e^{-0.015x}$ | 0.6554 |
| Control 2   | $y = 686.16e^{-0.016x}$ | 0.9408 |

According to the $R^2$ value (> 0.6), it close to 1.00 therefore its implies that the current sensor which being tested is valid. Each unit of CSMS has trendline equation (Table 1) that can be used to convert sensor response (Hz) to moisture content data. The sensor response which as independent variable (x) will produce moisture content value (y) when it put in the equation.

#### 3.2. Soil moisture profile and plant growth

The SFCW soil moisture in each area was shown in Figure 6. In horizontal direction, it is shown that the moisture at 0.2 m were higher than at 0.1 m. This result is obtained in all area. Soil moisture naturally able to penetrate upward due to evapotranspiration but its rate is lower than the downward
flow caused by bulk liquid flow. The location of leach pipe which is buried in the sand layer is the main factor that affected the distribution of soil moisture in horizontal direction.

![Figure 6. Soil moisture profile of SFCW](image)

![Figure 7. Soil moisture profile at 0.2 m depth and control garden](image)

The soil moisture profile of SFCW at 0.2 m depth varies during observation as shown in Figure 7. This result shows that every house owner uses the toilet, the septic tank effluent its flow into sand
layer. Sand and gravel layer are able to absorb the waste water and provide moisture for plant to grow. Comparison between measured area show that there was a significant difference between soil moisture of 0.25 and 0.75 m area. During the observation, area with 0.25 m distance has higher soil moisture compared to 0.75 m. This result shows that wastewater needs to be penetrated horizontally due to mass diffusion. In the other hand, soil moisture in control was found to be higher than SFCW. This result because the control uses different medium compared to SFCW. Latosol soil which is used in control garden has higher moisture capacity than sand or gravel layer on SFCW.

Plant growth analysis was conducted by comparing stem length of plant in SFCW and control garden. As shown in Table 2, stem growth rate of control plant was higher than all plant in SFCW. Stem growth rate which closer to leach pipe (Area B and C) is higher than the plant growth rate oat 0.75 m (Area A and D). This result indicates that soil moisture distribution has positive correlation with stem growth rate.

| Area | Stem growth rate (cm/day) |
|------|----------------------------|
| Control Plant | 0.70 |
| A | 0.27 |
| B | 0.38 |
| C | 0.47 |
| D | 0.27 |

4. Conclusion
The results show that all units of CSMS were valid to measure soil moisture content of SFCW. Its can be concluded that soil moisture profile of SFCW are varies both in vertical and horizontal direction. The deeper soil the higher soil moisture content, the closer distance to leach pipe the higher moisture content. Moreover, the soil moisture of SFCW in this study, affect stem growth rate of Ipomoea reptans Poir.

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