Application of paper disc velocimeter for groundwater flow measurement in tropical peatland

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Abstract. This paper presents the application of paper disc velocimeter (PDV) for groundwater flow measurement in tropical peatland. The PDV is a simple and low-cost method used without electricity that is developed by Yamaguchi University to measure groundwater flow. This method was applied to understand the groundwater hydraulic in the tropical peatland as the impact of rewetting efforts using canal blocking. A study site at Lukun village, Kepulauan Meranti Regency, Riau in Pulau Tebing Tinggi peatland hydrological unit (PHU) was picked up for the application of this method. Five deep wells in each transect of three transects totally were prepared for the measurement using PDV. The Transect-1 and Transect-2 were located at the upstream side of canal block with a distance of about 400 m and 100 m respectively. The Transect-3 was located on the downstream side of the canal block with a distance of about 100 m. The results showed that the groundwater velocity in the upstream side of canal block tends to lower than that in the downstream side. This was because the groundwater level in the upstream was maintained in a stable condition due to the canal blocking. This finding showed the impact of canal blocking on the rewetting effort in the tropical peatland.

1. Introduction

Peat is a soil that was formed from the decomposition of vegetations in the lowlands which is always high saturated condition which makes the peat contain more than 75% organic content [1]. Peat is an organic material that is formed naturally from the remnants of plants that are imperfectly decomposed with a thickness of more than 50 cm and accumulates in the swamp. The land is specially made by the remnants of vegetation that accumulates over a long period and makes peat soils [2]. The unique physical characteristics of peat that need to be understood include maturity, color, specific gravity, porosity, irreversible dryness, subsidence, and flammability. In terms of maturity, peat varies in maturity because it is formed from different materials, environmental conditions, and time. Peatland is very vulnerable against fire in the dry season and it is very difficult to be stopped due to the underground fire [3].

Riau Province holds the largest area of tropical peatland in Indonesia. Unfortunately, forest fires occur almost every year, especially during the dry season in Riau peatland. In the dry season, the peatland should be as a water-retaining layer functions and releases water slowly [4]. In natural conditions, peatlands are not flammable because of their sponge-like nature, which absorbs and retains water optimally so that in the rainy and dry seasons there is no difference in extreme conditions. Peatland fire is a fire that occurs in the peat area caused by human actions or due to natural factors such as drought or dry season. One of the efforts to prevent the problem of drought and forest fires is by rewetting activities using canal blocking [5]. Generally, the goal of rewetting degraded peatland is to restore the hydrological function of peat which increases the wetness and peat moisture. The basic principle of canal blocking is to hold and to store water as long as possible within the peatland hydrological unit area.

The groundwater flows around canal blocks should be analyzed to understand the effect of canal blocking in the peatland. The analysis was carried out using a paper disc velocimeter (PDV) device that was installed at the monitoring deep wells around the canal block. The PDV is a simple and low-cost method used without electricity that is developed by Yamaguchi University to measure groundwater flow [6]. Based on the laboratory
test, the PDV can be used to measure the groundwater velocity with a range of 0.03 cm/min – 0.3 cm/min and also the velocity direction with the accuracy of about 33% [7]. This method was applied to understand the groundwater hydraulic in the tropical peatland as the impact of rewetting efforts using canal blocking. A study site at Lukun village, Kepulauan Meranti Regency, Riau, Indonesia in Pulau Tebing Tinggi peatland hydrological unit (PHU) was picked up for the application of this method. Five deep wells in each transect of three transects totally were prepared for the measurement using PDV. The Transect-1 and Transect-2 were located at the upstream side of canal block with a distance of about 400 m and 100 m respectively. The Transect-3 was located on the downstream side of the canal block with a distance of about 100 m.

2. Method

2.1. Study Area

The study was carried out at a research site which is located in Pulau Tebing Tinggi peatland hydrological unit (PHU), Kepulauan Meranti Regency, Riau Province, Indonesia as presented in Fig. 1a. The Pulau Tebing Tinggi PHU is one of the most priority areas for peatland restoration by the Indonesian government [8]. Based on the topography map, Lukun Village generally has a lowland and peatland area, with an area of 154.6 km². (see Figure 1b).

![Figure 1. Lukun Village, Tebing Tinggi District, Kepulauan Meranti Regency, Riau Province (a), the topographic map of Pulau Tebing Tinggi peatland hydrological unit (b)](image)

2.2. Experiment set up

Together with the measurement of groundwater flow, the other data were used for analysis the flow characteristics due to canal blocking in this study were elevation data and groundwater level data. The measurement of the groundwater level was carried out using PDV by submerging the sensor for 60 minutes in each deep well around the canal block (Fig. 2a). The deep wells were made using PVC pipe (Polyvinyl Chloride) with a diameter of 2 inches and a height of 2 m as presented in Fig. 2b. The sensor of PDV consists of a paper disc covered with some layers of sponges, as presented in Fig. 1c.

The measurements were made on 3 transects, namely Transect-1 in upstream, Transect-2 in middle, and Transect-3 in downstream as presented in Fig. 3. The deep wells in the first transect are 1-1, 1-2, 1-3, 1-4, 1-5, the deep wells in the second transect are 2-1, 2-2, 2-3, 2-4, 2-5, and the deep wells in the third transect are 3-1, 3-2, 3-3, 3-4, 3-5. The distance of each monitoring deep well is 1 m, 51 m, 101 m, 201 m, and 301 m from the canal. The cross-section of each transect is presented in Fig. 4.

The PDV tool uses ink spread on paper to represent the speed and direction of groundwater flow. Figure 5 shows the paper disc before and after used for measurement, and after ImageJ analysis. After submerging the PDV sensor for 60 minutes, the dotted ink in the center of paper disc will be dispersed because of the groundwater flow. There are two methods to interpret the measurement result, such as using naked eye analysis and using image analysis. The naked eye analysis measures the length of the ink tailing (α) in the paper disc, and the velocity magnitude can be calculated using Eq. 1 [6]. If the result is smaller than 0, then there is no flow.

\[
\text{Velocity} = \frac{\alpha - 0.194}{19.765}
\]  

(1)

Image analysis using ImageJ application is used to delineate the ink dispersion so that the direction and the length of the tailing can be observed. Based on this, the velocity magnitude and the direction can be justified. The results of the image analysis on the paper disc using ImageJ application are XM tailing, XM Dot and YM
tailing, YM Dot as presented in Fig. 6. The velocity magnitude using this method can be calculated using Eq. 2 [6].

\[
\text{Velocity } 60 \text{ min} = \frac{1}{10.761} \times 0.1 \times (\text{XM dot} - \text{XM Tailing})^2 + (\text{YM dot} - \text{YM Tailing})^2)^{0.5}
\]  

(2)

Figure 2. Method of groundwater flow measurement in the peatland (a), using deep well (b), and PDV sensor (c).

Figure 3. The configuration of deep wells in each transect and canal blocks.
Figure 4. Cross-section of each transect

Figure 5. The paper disc before used, after used and after analyzed using ImageJ

Figure 6. Velocity analysis of paper disc tailing using ImageJ application
3. Result and Discussion

3.1. The result from ImageJ and naked eye analysis

Figure 7 shows the comparison of velocity results using ImageJ and naked eye analysis on each deep well. The velocity magnitudes tend to have a similar trend between the analysis using the naked eye and using ImageJ analysis. Both methods show that the velocity in the Transect-1 and Transect-2 have a lower velocity and in the Transect-3 have a higher velocity. Some points have the same velocity magnitude as the result of the analysis using the naked eye and ImageJ. However, some points have different velocity magnitude. This is because of the ink can be finely identified using ImageJ analysis, so that the ink tailing can be delineated accurately. The naked eye analysis has a high potential for human error.

![Figure 7. The comparison of velocity result using ImageJ and naked eye analysis](image_url)

3.2. Groundwater flow around canal block

Measurement of the groundwater flow around the canal block was carried out in order to understand the impact of canal blocking for rewetting effort in tropical peatland. The map of velocity magnitude and direction as a result of measurement from 15 deep wells are presented in Fig.8. The map shows that the velocity in Transect-3 has a higher magnitude than that in Transect-2 and Transect-1 (also see Fig. 7). This phenomenon was caused by canal blocking. Canal blocking made the water level in the upstream side of the canal increase and the downstream side was not impacted. There was a different water elevation (head) between the upstream and downstream sides of the canal block because of canal blocking. The increasing water level in the upstream side of the canal block penetrated the peatland area and made the groundwater level higher. This made groundwater level in the upstream of canal block higher than that in the downstream, as presented in Fig. 9. As a result, the head in the Transect-3 was higher that caused the groundwater velocity higher than before canal blocking. However, the groundwater flow in the upstream side of the canal block tends to lower than that on the downstream side. This was because the groundwater level was maintained in a stable condition due to the canal blocking. This finding showed the effectiveness of canal blocking on the rewetting effort in the tropical peatland.

Theoretically, the groundwater flows from high to low groundwater levels. The measurement using PDV also can identify the direction of groundwater flow. The maps of the direction of groundwater flow as a result of PDV measurement are presented in Fig. 8 and Fig. 9. The flow direction showed a good agreement with the theory that the flow should be from high to low groundwater level. Most of the measurement at the deep well in Transect-3 showed the flow direction to the downstream which has the lower groundwater level and high head due to canal blocking. However, the groundwater flow direction in the Transect-1 and Transect-2 were not in a similar pattern but were still follow the basic theory of flow. This was because of the groundwater level in the upstream side of canal block were in a stable condition due to the canal blocking. There was no significant difference in the groundwater level in the upstream peatland of canal block. However, the flow should be going to the peatland area from the canal if the water level in the canal starts to increase. This condition usually occurs at the beginning of the rainy season.
Figure 8. The map of groundwater velocity magnitude and direction

Figure 9. The map of groundwater level elevation and the flow direction
4. Result and Discussion

This paper presents the application of paper disc velocimeter (PDV) for groundwater flow measurement in tropical peatland. The PDV is a simple and low-cost method used without electricity that is developed by Yamaguchi University to measure groundwater flow. This method was applied to understand the groundwater hydraulic in the tropical peatland as the impact of rewetting efforts using canal blocking. The results showed that the groundwater flow in the upstream side of canal block tends to lower than that in the downstream side. This was because the groundwater level was maintained in a stable condition due to the canal blocking.

However, there was a large head difference between upstream and downstream of the canal block that made the Transect-3 had a higher velocity. This finding showed the effectiveness of canal blocking on the rewetting effort in the tropical peatland.

5. References

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