Groundwater Flow Analysis at Coastal Peatland Area of Bengkalis Island Using Paper Disk Velocimeter (PDV)

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Abstract. Bengkalis Island is an island with about 89% of its land area consisting of peatlands. Because of the land use conversion from peat swamp forest to plantation and shrubs, the island has experienced massive degradation, such as abrasion, subsidence and land fires. The abrasion at western area of Bengkalis Island has occurred since the last 30 years with an abrasion rate up to 30 m/year. The previous studies showed that this is because of unbalanced hydrological conditions. The more advanced research related to groundwater flow impact on degraded peatland in Bengkalis Island is important in order to understand the mitigation alternative. To study the groundwater flow on the peat coast of Bengkalis Island, this study used Paper Disk Velocimeter (PDV) for measuring at 2 monitoring wells. The measurements were carried out at a depth of 2 m and 5.5 m and a depth of 2 m, 3 m and 4 m for Well-1 and Well-2 respectively. All measurements were carried out for 3 times on different month. This research found that the groundwater slope dropped significantly near the coastal line. This made the groundwater discharge to the coastal area become higher that may cause failure on the coastal cliff. The failure was identified as the initial phenomenon of the abrasion mechanism in the Bengkalis coast.

1. Introduction

Tropical peatlands cover an area of around 40 million ha, half of which are found in Indonesia. Peat is essentially the result of the accumulation of material left over from vegetation over thousands of years ago consisting of ±50% carbon element so that Indonesia’s peatlands are very important have to be reserved for global climate control [1]. The largest peatland area is located on the island of Sumatra, which is 6.4 million hectares, with the largest distribution on the East Coast of Sumatra Island. According to data about 60% of peatlands in Sumatra or 3.8 million hectares are located in Riau province. Bengkalis regency has the second largest peatland area in Riau which is situated in the mainland of Sumatera and in the islands of Bengkalis [2]. It was estimated that the peat volume of Bengkalis Island is to be in the range of 3.28–3.58 km³ [3]. The Bengkalis Island is one of the islands which are very vulnerable to coastal abrasion problems. Abrasion rate at Bengkalis island is very high, reaching 30 m/year since the last 30 years [4].

Government efforts for mitigation of the abrasion have been made, but did not cover most of Bengkalis Island, including Meskom Village [5]. In this case, the northern part of Meskom Village is very vulnerable to cliff collapse due to abrasion with an area of up to 50.8 m² [6]. Therefore, a field study was conducted in the Bengkalis Island coastal area to analyse the characteristics of groundwater flow as one of the hydrological units of the peat near the coast after the occurrence of coastal abrasion and accretion phenomena. In this case, the hydrological condition of the peat needs to be reviewed, focusing on groundwater level and groundwater velocity.
Groundwater level on the peatlands is relatively high where the groundwater level will affect groundwater flow due to the influence of gravitational potential. Groundwater will flow from the land with a higher water level to the lower one. Therefore, the movement of groundwater flow is relatively high due to the large porosity in the peatlands. The direction of groundwater flow lead to the coastal area that will have the impact on the abrasion phenomenon. It will have an impact on draining of peatlands due to channel leakage if it reaches the canal [7]. Thus, a case study was carried out by examining directly in the field to measure the velocity and direction of groundwater flow as a reference for further study on coastal peat areas in the village of Meskom, Bengkalis Island.

2. Method

2.1 Study area

This research was conducted at coastal peat in Meskom Village, Bengkalis Island, Indonesia as presented in Fig. 1. The study area is covered with palm oil plantations equipped with canals for water distribution and transportation. The research site is located about 200 meters distance to the coastal line. It was identified that the coastal area at this point has lost because of abrasion about 30 m/year [8]. The average peat depth of the study site is approximately 4.5-5.5 m. For measurement the groundwater level, 14 dipwells were made with a distance between points from 70 - 90 m. While the distance of the observation point for groundwater flow to the shoreline are 380 m and 280 m for N2W2 dipwell and N2C dipwell respectively. In addition, all of the dipwells ground surface elevation were measured using RTK-GPS.

2.2 Method

This study used Paper Disk Velocimeter (PDV) equipment developed by Yamaguchi University, Japan as presented in Fig 2. The equipment consists of several series of materials such as poles, sponges, sensors, and paper disc made from Maruman Company 126.5 g/m² and black ink: Canon BCI-6BK. Some dotted papers were inserted between the sponges in the equipment. During the measurements, the equipment was submerged into the groundwater for 60 minutes. The dotted ink on the papers then will spread that indicates the groundwater flow speed and direction during measurement.

The measurement using PDV was conducted directly in the dipwells for three time period of measurements, such as on 6 September 2019, 6 November 2019, and 12 January 2020. The measurement was performed at 2 points observation, i.e. N2W2 and N2C dipwell. The measurement depth were 2 m, 3 m and 4 m, at N2W2 site and 2 m and 5.5 m at N2C site. In addition to measuring flow velocity, groundwater levels were also measured at 12 other points with different monitoring points as presented in Fig.1.
Figure 3 presents a paper disc before used and after used for measurement. It can be seen a dot tailing of the doted ink in the paper disc because of the groundwater flow. The magnitude of the velocity can be analysed by image processing using ImageJ. Using image processing, it can be found XM Tailing, XM dot, YM Tailing and YM dot. The directions and the magnitude of groundwater flow can be estimated using the followings equations.

\[
\theta = \arctan \left( \frac{YM_{dot} - YM_{Tailing}}{XM_{dot} - XM_{Tailing}} \right)
\]

Velocity 60 min = \( \frac{1}{10.762} \times 0.1 \times \left( (XM_{dot} - XM_{Tailing})^2 + (YM_{dot} - YM_{Tailing})^2 \right)^{0.5} \)

\( \text{Figure 2. Method of groundwater measurement by using dipwell (a) and PDV sensor (b)} \)

\( \text{Figure 3. The paper disc before used, after used and after processing by ImageJ} \)

3. Results and Discussion

3.1 Result of Velocity Measurement

The results of the measurements using PDV and analysis are presented in Table-1. The measurement results show the magnitude and the direction of the groundwater velocity. The results show that the measurements on 6th September 2019 indicated the highest velocity both at N2W2 and N2C dipwell with the velocity magnitudes of 1.10 m/day and 2.31 m/day, respectively. This occurred because of the dry season condition that caused the level of drainability was very high. On the other measurements, the velocity shows lower magnitude than on 6th September 2019. The two other measurements were conducted on the rainy season. In the rainy season, the level of drainability was lower than in the dry season because the peatland was on the wet condition along the season.
Table 1. Velocity and direction of groundwater flow from measurement and analysis results

| Date              | Duration | Point | Depth m | Direction (°) | Velocity cm/minutes | Velocity m/day |
|-------------------|----------|-------|---------|---------------|---------------------|----------------|
| 6th September 2019| 60 Minutes| N2C   | 2       | 281.45        | 0.0763              | 1.10           |
|                   |          |       | 5.5     | 225.48        | 0.0391              | 0.56           |
|                   |          |       | 2       | 226.20        | 0.1603              | 2.31           |
|                   |          | N2W2  | 3       | 218.65        | 0.0200              | 0.29           |
|                   |          |       | 4       | 341.35        | 0.0160              | 0.23           |
|                   |          | N2C   | 2       | 139.41        | 0.0521              | 0.75           |
|                   |          |       | 5.5     | 354.06        | 0.0282              | 0.41           |
| 6th November 2019 | 60 Minutes| N2W2  | 2       | 125.19        | 0.0153              | 0.22           |
|                   |          |       | 3       | 101.71        | 0.0116              | 0.17           |
|                   |          |       | 4       | 145.14        | 0.0744              | 1.07           |
|                   |          | N2C   | 2       | 96.82         | 0.0600              | 0.86           |
|                   |          |       | 5.5     | 29.46         | 0.0522              | 0.73           |
| 12th January 2020 | 60 Minutes| N2W2  | 2       | 298.90        | 0.0367              | 0.53           |
|                   |          |       | 3       | 145.61        | 0.0794              | 1.14           |
|                   |          |       | 4       | 139.94        | 0.0351              | 0.51           |

3.2 Mapping of GWL and Velocity

The map of the groundwater level (GWL) and the groundwater velocity (GWV) were overlaid in order to understand the correlation between them, as presented in Fig.4. The map of GWL and GWV from the analysis and measurement on 6 September 2019, 6 November 2019, and 12 January 2020 are presented in Fig. 4 (a), (b) and (c) respectively. The figures show that the erosion process are still occurring in the Bengkalis coast. The N3W3 and N3W2 dipwells were initially still in the inland during 6 September to 6 November 2019, but they were in coastal area on 12 January 2020, as presented in Fig.4. These phenomena made groundwater slope dropped significantly on the GWL map on 12 January 2020. This made the groundwater discharge to the coastal area become higher that may cause failure on the coastal cliff. The failure was identified as the initial phenomenon of the abrasion mechanism in the Bengkalis coast [9].

The direction of groundwater flow is theoretically from higher to lower GWL. The results of the groundwater flow measurement using PDV showed that most of the flow direction were from higher to lower GWL as presented in Fig. 4 (a), (b) and (c). The velocity magnitudes from the measurements on 6 September 2019 showed that at N2W2 dipwell has higher velocity than that of N2C dipwell. This was occurred because the groundwater slope at N2W2 was higher. The similar phenomena also occurred in the measurement on 6 November 2019 and 12 January 2020.
3. Measurements

- Measurement on 6th November 2019
- Measurement on 12th January 2020

Figure 4. The magnitudes and directions of groundwater flow on each time measurement

4. Conclusions

This research used Paper Disk Velocimeter (PDV) to study the groundwater flow on the peat coast of Bengkalis Island. This research found that the groundwater slope dropped significantly near the coastal line on the GWL map on 12 January 2020. This made the groundwater discharge to the coastal area become higher that may cause failure on the coastal cliff. The failure was identified as the initial phenomenon of the abrasion mechanism in the Bengkalis coast. This research also found that in the measurements on 6th September 2019 indicated the highest velocity both at N2W2 and N2C dipwell with the velocity magnitudes of 1.10 m/day and 2.31 m/day, respectively. This occurred because of the dry season condition that caused the level of drainability was very high. In the rainy season, the level of drainability was lower than in the dry season because the peatland was on the wet condition along the season.

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