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Research Paper

Variability of Water Table Elevation and Flow Response of Tropical Peatland Case Study at Pulau Padang, Riau, Indonesia

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ABSTRACT

Peatland is a type of soil characterized by high water content. Using peatlands for plantation is accompanied by the presence of a channel. It causes water table decreasing to a certain depth that will increase the risk of fire. This study aims to observe characteristics of water table level in order to reveal the peatlands hydrology transformation. The study is conducted in Pulau Padang, Riau Province of Indonesia, which is a drained peatland that has been developed for industrial crop cultivation. The land is managed by different two groups, which are maintained by the local community and by private companies. An analysis is carried out by using a balance of water budget in peatland. The results show that there are correlations between water management with the state of water table elevation, especially the presence of channels and their management. The decreases of water table in local community areas are higher than that in companies' land with variety in higher values. This phenomenon occurs because there are no canal blocks on the peatland, which is managed by the local community so that the rise and fall of the water surface occur naturally.

1. Introduction

Deforestation, especially peat forests, has received serious intention from researchers. Some of articles cover forest point of view, such as the area of forest loss (Page and Rieley, 1997; Curran, *et a*l. 2004), the amount of carbon and its balance in peatland (Suzuki *et al*., 1999; Tuittila *et al*. 1999) relationship between vegetation and water table especially in the drained peatland (Tuittila *et al*., 1999; Breeuwer *et al*., 2007; Potvin *et al*., 2015; Ruseckas *et al*., 2015) and reduced number of specific plants (Curran *et al*., 1999; Haapalehto *et al*., 2010). Other articles present characteristics of hydrodynamics or hydrology, such as alteration in hydraulic conductivity and interaction between peatland hydrodynamics, climate and carbon sink (Curran *et al*., 1999; Komulainen *et al*., 1999; Curran *et al*., 2004; Briggs *et al*., 2007; Wösten *et al*., 2013; Harenda *et al*., 2018). The significant roles of peat, including swamp, are its ability to store carbon stocks (Vitt 2008; Harenda *et al*., 2018), and a major factor for runoff production (Bay 1969; Holden *et al*., 2011). The others are as a source of water and even as an alternative to decrease floods (Holden, 2005; Acreman and Holden, 2013), and it can be an essential research object. The analysis is needed to manage peat soils to provide benefits that are greater than the losses incurred due to the converting function.

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The total peat area is estimated to reach 2.84% of all the world's land (Xu *et al*., 2018) with tropical peat is 11% of the global peat area (Page *et al*., 2011). Peatlands contain soil carbon stock reaching to 20%. The volume of tropical peat carbon is 15%-19% of the global peat carbon. A 77% of tropical peat is in Southeast Asia, in which the biggest value resides in a single country i.e. Indonesia which is around 65% (Wu *et al*., 2010; Page *et al*., 2011). Indonesian peatlands become significant in recognizing the characteristics of tropical peatland, including volume of carbon due to its role as a dominant peatland in Southeast Asia, and the differences with subtropical peatland (Murdiyarso *et al*., 2019; Wahyunto *et al*., 2016; Shimada *et al*., 2001; Bispo *et al*., 2016).

Peatlands in Indonesia, as part of tropical type, has been a concern and subject of research for a long time (Brady 1997; Curran *et al*., 1999; Shimada *et al*., 2001; Page *et al*., 2002; Miettinen and Liew, 2010; Ritzema *et al*., 2014; Uda *et al*., 2017). Peatlands are distributed in Sumatra Island, Kalimantan Island, Papua Island, and a small amount in Sulawesi Island (KMLH, 2019). Sumatra peatlands have a similar type with that in Kalimantan, i.e. a deep in-depth and have undergone drainage, but the level of research is to Sumatra type is not as much as research to Kalimantan peatlands (Page *et al*., 2002). One of them is a research on Pulau Padang (Brady, 1997). Some of them serve to provide recommendations for other tropical countries that have not may convert peatlands yet, such as Peru and the Republic of Congo (Murdiyarso *et al*., 2019); others are seen in Kalimantan, where the influence is dominant during forest loss (Curran *et al*., 2004; Miettinen and Liew, 2010) or the amount of carbon was released by peatlands in the fires in 1997 (Page, *et al*., 2002).

Management of peatlands requires drainage to achieve a water table level that is appropriate for plants. Peatland, which is saturated or even flooded, will need special treatment before it can be used as plantation or agriculture. The existence of drainage is significant so that they have a water content according to the types and the function of plants (Mitsch and Gosselink 2015; Breeuwer *et al*., 2009; Potvin *et al*., 2015). Drainage systems on peatland caused various effects. There is the differentiation between the top layer and down layer, a change in the composition of acrotelm-catotelm, various groundwater level, and change the fluctuation of overflow and carbon reduction. (Grand-Clement *et al*., 2015; Daniels *et al*., 2008; Holden *et al*., 2006; Holden, 2005).

Water table level state is the core to understand the changes that occur in drained peatlands (Daniels *et al*., 2008; Wosten *et al*., 2008; Erwin 2009; Postila *et al*., 2015; Howie SA and van Meerveld, 2013; Ruseckas *et al*., 2015). The relationship between water table elevation and peatlands hydrology is investigated to determine its potential against fire threats (Novitasari *et al*., 2019). A study about the relationship between water table elevation and peatland conditions was carried out by Wosten *et al*. (2008). It resembled the actual term by using the hydropedology model. SIMGRO (Simulation of groundwater flow and surface water levels) model was used to assume water level state. The study was conducted in Kalimantan and a map was produced. It describes peatland vulnerability with an estimated groundwater level based on the characteristics of hydraulic conductivity and soil moisture content.

The approach that can be used to characterize swamp hydrology, including peatland other than water table elevation, is the water balance analysis (Holden, 2005; Mitsch dan Gosselink, 2015; Grundling *et al*., 2015; Gracz *et al*., 2015; Edom *et al*., 2010). The hydrological and hydraulic state of peatlands can be identified by changing the water table level, altering hydraulic conductivity and fluctuating of flow rate in the channel. (Postila *et al*., 2015; Holden *et al*., 2006; Edom *et al*., 2010).

Study of runoff on peatlands (Bay, 1969; Brown, 1988; Stewart and Lance, 1991; Evans *et al*., 1999; Gracz *et al*., 2015) had been done to understand how runoff was generated in peatlands. Research of Holden and Burt (2003) indicated that several important factors in generated runoff are land covering, topography and special ditch. Most runoffs occur at shallow depths of a few centimeters from the surface and the runoff response declines rapidly towards the depth, and rainfall intensity has a positive correlation with filtration rate (Holden and Burt, 2002). Almost all overland flows occur on the surface of peatlands, and a small portion of them occurs in a depth of less than 10 cm (Holden and Burt, 2003) although the thickness of peat is more firm.

Research on peatland in the tropical area such as in Indonesia, has differences with the other four-season countries, e.g. very thick peat depths more than 12 meters as it is found in Pulau Padang, Riau Province (Brady, 1997; Page *et al*., 2011). Pulau Padang is a deep peatland that has been restrained and converted into a variety of plantations (Karyanto, 2000). More detail and locally scale research in a particular area is needed to understand how peatlands transform during its management period (Curran *et al*., 2000; Shimada *et al*., 2001; Whitfield *et al*., 2009). In addition to land that has experienced canalization such as Pulau Padang, the necessity becomes more significant. Further studies will be required to investigate whether hydrological characteristics change will be found after different features and management of using of peatland for plantation or agriculture has been applied.

Two different characteristics are available in Pulau Padang i.e. the area is managed by the corporation, and by the community. This study aims to: 1) to compare the state of the water table level on both of the characteristics, 2) to analyze the state of the groundwater by frequency of occurrence and 3) to describe the process of runoff channel showed a response of peatlands to rainfall.

2. Materials and Methods

The study was conducted on one of the drained tropical peatlands in Riau Province and was carried out for two months, from November to December 2017. It was arranged at two locations representing community-managed land and the company's concession area. More explanations can be found in the description below.

2.1 Site Description

Pulau Padang is one of a series of four main islands within the Kepulauan Meranti Regency, Riau Province. Pulau Padang is a Peatland Hydrological Unity (*Kesatuan Hidrologi Gambut*/ KHG) with the area of 1.114,04 km^2. Geographically Kepulauan Meranti district is located 0° 42' 30"- 1° 28' 0" N and 102° 12' 0"- 103° 10' 0" E. The climate in Pulau Padang as well as in the Kepulauan Meranti district region is temperate with maximum air temperatures ranging from 25°C–32°C (BPS Kepulauan Meranti District, 2017). Figure 1 shows the study area.

Fig 1. Research location

Pulau Padang has a flat topography with a maximum height of 15 m above mean sea level (MSL). The thickness of peat on Pulau Padang, as in other peatlands in Indonesia such as Kalimantan, tends to be more than three meters. The primary type on Pulau Padang is 6 meters or more in-depth so that it can be categorized as deep peat, depth of groundwater tends to be more stable than shallow peat (Brady, 1997).

2.2 Field Mesurements

The important hydrological data that are needed for this research are rainfall data, flow data, and water table elevation (WTE) data. Data collected is daily rainfall measured by automatic rain gauge (ARR) for 10 minutes interval series. Two sets of equipment are installed in Sei Hiu Village and Bagan Melibur Village. The locations and installations of the pieces of equipment are illustrated in Figure 2 and Figure 3. Figure 3 shows that water table elevation measurement was installed at the center of the area (WET measurements) and automatic water elevation and rainfall (WET measurement) settled at the edge of the zone. The arrangement of materials is needed to observe the state of the groundwater level condition and its relationship with the water level in the channel.

Fig 2. Location of water measurement equipment

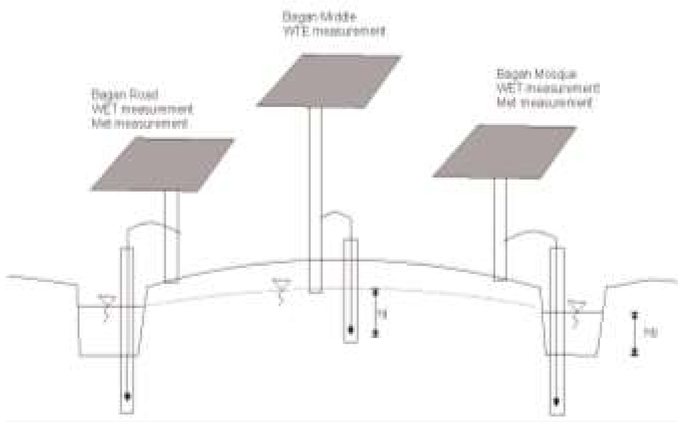

Fig 3. Sketch of measurement equipment.

2.3 Secondary Data

There are two kinds of water table elevation (WTE) information. Those come from the results of measurements, which is called primary data. The others come from monitoring activity that has been done by Riau Andalan Pulp Paper (RAPP) as secondary data. Secondary data cover the RAPP area which consists of industrial plantations (IP), they are presented in three stations, i.e. PPD 1, PPD 2, and PPD 9; three natural forests (NF) i.e. PPD 3, PPD 4 and PPD 10 and one buffer zone area (PPD 8). Data come from the year 2015 to 2017 at intervals of one hour. Even though data was started from 2015 but not all of them are complete, so the analysis will have its limitation here.

2.4 Water Balance Equations on Peatlands and Analysis of Discharge on Channels

Water table elevation data change can be used to study the influence of the presence of channels and land cover on groundwater fluctuations. The water balance equation can analyze alteration in the groundwater level. The formulation will be different for drained peatlands with network systems than the one which is still intact. It happens because the presence of canals will significantly influence the groundwater fluctuations that are affected by the rate of groundwater wear by the process of subsurface runoff.

The general equation of water balance in peatlands in a rain state prior to an application of the canal network based on the hydro meteorological cycle is as follows:

$$\Delta S = P - ET - RO - I \qquad (1)$$

where:

P : rainfall (mm/day),
ET : evapotranspiration (mm/day),
RO : surface flow (mm/day),
I : infiltration (mm/day),
ΔS : water storage change (mm/day).

The discharge that occurs for each rain event is calculated in the description below. The total runoff volume leading to the canal (VRO) is equal to the surface runoff volume (SRO) coupled with the subsurface runoff volume (SSRO) and changes in groundwater storage can be stated as follows.

$$\Delta S = \sum I - \sum O \qquad (2)$$

$$\Delta S = VP - (VRO + VET) \qquad (3)$$

$$Q_t = \frac{VRO}{dt} = \frac{dh}{dt} \times B \times L \qquad (4)$$

with

$$VRO = dh \times B \times L \qquad (5)$$

where:

ΔS : change in water storage volume (m^3),
$\sum I$: total of inflow = volume of rainfall (m^3),
$\sum O$: total of outflow = runoff + evapotranspiration (m^3),
VP : rainfall in volume (m^3),
VET : evapotranspiration in volume (m^3),
VRO : volume of total direct runoff total flow to canal (m^3),
Q_t : discharge in t time (m^3/s),
dh : rainfall depth (m)
dt : time interval (second),
B : wide of the channel (m),
L : length of the channel (m).

3. Results and Discussions

Peatland management will distinguish the peat hydrological states that have been managed. The peatland that was maintained by the community have simple characteristics, have not implemented a regular system, and have almost no canal blocking. On the other hand, the land runs by the company have higher network density and regularity of the channel system including the presence of canal blocking.

3.1 Analysis of Changes in Water Table Elevation to Water Management

The secondary data were examined with the percentage of secondary data presentation from WTE events. The canal is regularly monitored by cooperate staff, including the natural forest and the buffer zone. The IP includes the main channel between two blocks along (1)
with mid-channel inside the block.

The analysis results show that there is a wide variation between the lowest and highest water table elevations (WTE). Some value exceeds the government requirements, which is 0.4 m below the surface (RI, 2014), and the graph presented in Figure 4.

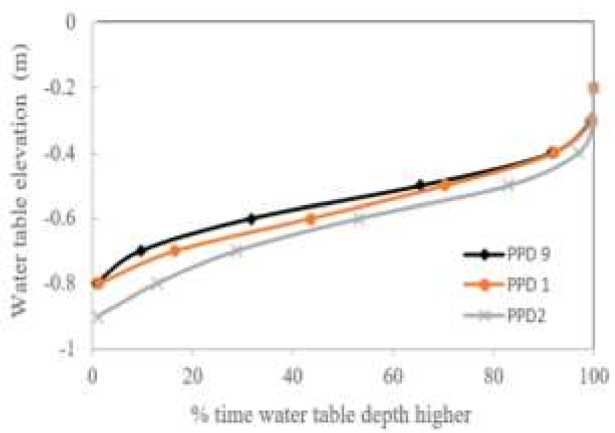

Fig 4. Water table frequency curves for area of IP.

Figure 4 shows that generally most of the groundwater level always exceeds the allowed level. 80% of the value of PPD 1, PPD 2 and PPD 9 are higher than the allowable level. The state of WTE in PPD 4 (Figure 5) is higher than -0.4, reaches around 60%, which is the best value. Therefore, it can be concluded that the water table elevation during the study period is not in a recommended state. It can be analyzed that the chance of a fire associated with the groundwater level will be higher. For another region, the trend can be explained in Figure 5.

The buffer zone (PPD 8) in Figure 5 shows the most stable state for water table level trends. Forest areas (PPD3, PPD4, and PPD 10) should have more stable groundwater depths, but in fact, they were not found. The area where groundwater depths reached -1.3 m should have shallow WTE than -0.4. Furthermore, more than 80% of the depth is at an insecure elevation that exceeds the recommended value, as can be seen in Figure 5.

IP area and the buffer zone have *Acasia Crasicarpa* as the homogenous area, while forest has more *Melaleuca Cajuputi* (*Gelam* in local language) rather than other plants. As the type of land management and plantation do not determine to water table elevation condition, therefore, it is needed to recognize another determinant factor.

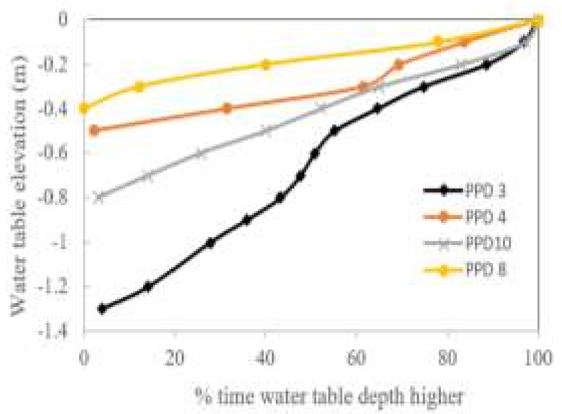

Fig 5. Water table frequency curves for natural forest and buffer zone.

Other than the type of plants, the main difference between the three areas is the water management. On the IP land, the water system is built by main canals and middle canals. The main canals is located in the boundary between the blocks, while the middle canal is in the center of the block. The buffer zone only has the main canal and there is no canal system in the natural forest except for a little ditch.

The large canal regulates all inflow and outflow of the area and can even hold or allow flow to other areas Whilst the mid canal regulates water intern the block so that it can be assured the plants will never be flooded. It can be understood why in the buffer zone where there is no mid canal, water level elevations always are at higher than 0.4 m even more, and sometimes it flooded which is not a perfect condition for the plants.

The analysis is performed using rainfall data from automatic rain gauges and water table level data from automatic water level recorder. The following graph is obtained from the two pieces of equipment. Analysis of water table level and presentation of events is presented in Figure 6. It shows the condition of water table elevations at two locations where data were taken during the study. The noticeable difference is the antecedent of the groundwater as at Bagan Melibur Village reaches a depth of -1.9 m while Sei Hiu Village is only -0.7 m. Figure 6 shows that there are differences in the trend of water table level changes in the two areas. Bagan Melibur Village tends to have a high level of variability, i.e. the water level ranges from -0.6 m to -1.9 m, while it in Sei Hiu Village only ranges between -0.4 m to -0.6 m. According to government regulations, it can be concluded that Sei Hiu Village is categorized into safe limits, while Bagan Melibur Village is categorized into hazardous areas. They tend to have a higher risk because the water levels reached up to -1.9 m at the beginning of the wet season.

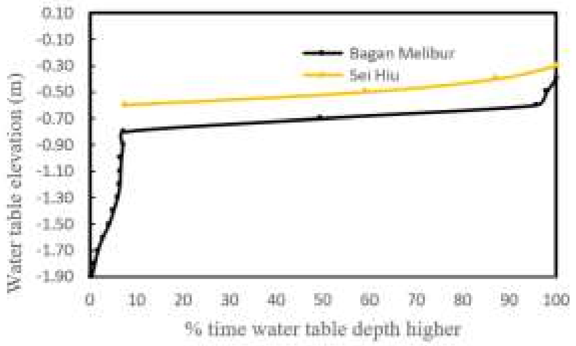

Fig 6. Water table frequency curves for Bagan Melibur Village and Sei Hiu Village.

In Bagan Melibur Village area, it can be seen that the water table elevation that is below 40 cm takes place less than 10%, which means that nearly 90% of the depth of the water table altitude is not at the recommended level. In Sei Hiu Village area, the water table level that is lower than 40 cm takes place more than 70% so that the water depth limit that exceeds the recommended limit occurs at a maximum of 30%.

The difference between the two zones as the causes of these results can be found in Bagan Melibur Village which is a community-managed area that does not yet have canal blocks. It means it does not have a scheme that can be used to hold water so the rainwater directly flows as runoff to downstream and does not have time to influence the water table level change on the land.

While Sei Hiu Village is managed by the company and has canal blocks, it has the opportunity to hold water. It happened on the preferred channel section so that if the land started to dry, the water is not allowed to flow downstream. This situation makes alterations in the water table level in Sei Hiu Village tend to be better than Bagan Melibur Village area. Comparing to the study from Holden *et al.* (2011); this research has the main difference in interval variability in WTE that ranges from -0.4 m to -1.9 m, while it in Holden *et al*. (2011) only ranges from +0.1 m to -0.6 m. The difference result between tropical peatlands with subtropical still needs to be revealed to have a deeper understanding of each characteristic. The presence of canal blocks in Central Kalimantan peatlands (Ritzema *et al*., 2014) has raised the water level significantly to elevations above -0.4 m as previously reached below -1.22 m, however, it was unable to maintain the water level in the dry season.There is a positive correlation between alteration in water table level and the presence of drainage channels (Luscombe *et al*., 2016; Page *et al*., 2009) that is artificial drainage decreases the extent of the water table. In this study, both locations have a human-made channel, and the depth of the groundwater is various, but they are strongly influenced by the rain which is consistent with research on peatlands in Kalimantan (Ritzema *et al*., 2014).

The hydrological response to the previous low groundwater conditions (antecedent) shows that the discharge rises rapidly while the groundwater level tends to be flat and even static (Daniels, *et al*., 2008). In the beginning of rainfall season, the antecedent height of groundwater level at Bagan Melibur Village and Sei Hiu Village are -1.9 m and -0.6 m respectively. In this study, the Pulau Padang state, when rainfall fell in Bagan Melibur Village then water table level rose rapidly to a height of -0.8 m with antecedent height was -1.9. Furthermore, it took a long time to rise to an elevation of -0.7 m. When the rain prolonged the water table only rose gently until it reached a stable state at -0, 4 m so that the situation was different from Daniels *et al*. (2008) study in South Pennines, UK.

3.1. Analysis of Flow Response to Rainfall and Water Table Level

Drainage has a considerable influence to generate flow and spatial based groundwater (Holden *et al*., 2006; Wosten *et al*., 2008; Luscombe *et al*., 2016) therefore on a drained peatland such as at Pulau Padang, it is necessary to do a spatial based flow analysis. They are laid on different topography, i.e., Sei Hiu Village is located in the north part of the island and Bagan Melibur Village is located in the southern area. Some rain has occurred during the period of data collection, as shown in Figure 7 and Figure 8 presents the relationship between rainfall events with the generated discharge flow.

Table 1. Rainfall intensity and WTE in December 3, 2017 event at Bagan Melibur Village .

No	Time happened	Rainfall Intensity (mm)	Water Table Elevation WTE (m)
1	04:50	0	-0.659
2	05:00	0	-0.656
3	05:10	0.3	-0.655
4	05:20	8.4	-0.643
5	05:30	6.6	-0.589
6	05:40	1.8	-0.555
7	05:50	2.7	-0.533
8	06:00	1.8	-0.517
9	06:10	0.3	-0.555
10	06:20	0	-0.545
11	06:30	0	-0.543
12	06:40	0.3	-0.543
13	06:50	0.3	-0.537
14	07:00	0	-0.535
15	07:10	0	-0.535

The previous condition of water table level showed a quite high value as in the rain of December 3, 2017 (Table 1 and Figure 7). It can be assumed that there is a small increase in the water table level. This is due to the high previous groundwater level, which has reached -0.659 m.

After one hour of the rain with a total rainfall of 21.6 mm, the groundwater level rises to -0.5 m. It can be concluded that the groundwater rise is smaller than previous rainfall events where the groundwater level was still low because it was at the beginning of the rainy season at November 6, 2019 event as shown in Figure 8. In this event the groundwater level was initially at the position of -1.179 m and in the first 20 minutes with a rainfall height of 6.3 mm, there is a discharge 60 L/sec and the water level is still in the number -1.179. Then one hour later, the groundwater level has become -0.945 m with a total rainfall of 34.9 mm (Table 2).

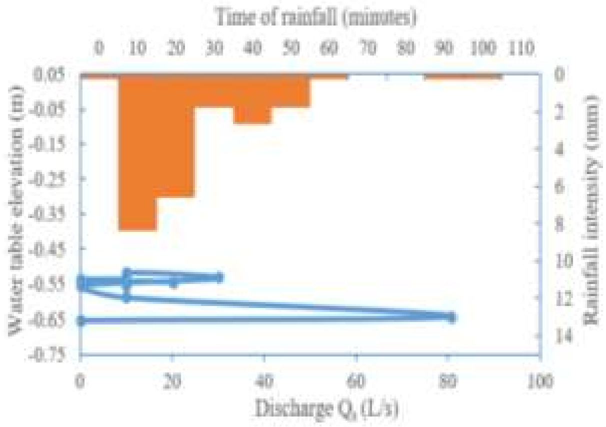

Fig 7. Profile rainfall and discharge vs water table elevation on December 3, 2017.

Table 2. Rainfall intensity and WTE in November 6, 2019 event at Bagan Melibur Village

No	Time happened	Rainfall Intensity (mm)	Water Table Elevation WTE (m)
1	16:10	0	-1.179
2	16:20	2.7	-1.179
3	16:30	6.3	-1.179
4	16:40	9.6	-1.179
5	16:50	9.6	-1.165
6	17:00	4.2	-1.062
7	17:10	2.7	-0.945
8	17:20	1.2	-0.787
9	17:30	0.9	-0.667
10	17:40	0.6	-0.556
11	17:50	0.6	-0.491
12	18:00	0.3	-0.443
13	18:10	0.3	-0.413
14	18:20	0	-0.395
15	18:30	0	-0.389
16	18:40	0	-0.387
17	18:50	0	-0.387

Table 1 shows that the increase in water table level continues even though the rain begins to decrease and one hour later the water table level has reached -0.4 m and after that the groundwater level is relatively constant. The difference in response to the hydrological state in an area is mainly determined by the heterogeneity of the region spatially and temporally. It is included the characteristics of each peatland (Parry *et al*., 2914).

The study result shows that the discharges rise either moderate (Figure 7) or high (Figure 8), which is different from the result of Daniels *et al*, 2008, where the groundwater level rises slowly or even tends to be static. In areas that have been drained, the profile of flow is sharper, thus the flow quickly reaches the peak while there is longer in peat intact with the original channel flow (Holden *et al*., 2006). In this study, the drained peatland has been managed for cultivation. Moreover, it can be seen that when there is rain, the water becomes direct runoff and reaches a peak and there is a similar phenomenon with previous research. Figure 9 presents the discharge alteration during a rainfall event, which is compared to the situation in South Pennines UK by Daniels, *et al*., 2008. It could be concluded that in low groundwater conditions, tropical peatland shows the same trend with that in sub-tropical regions.

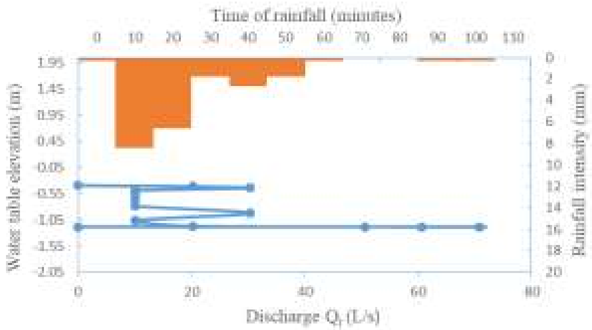

Fig 8. Profile rainfall and discharge vs water table elevation on November 6, 2017.

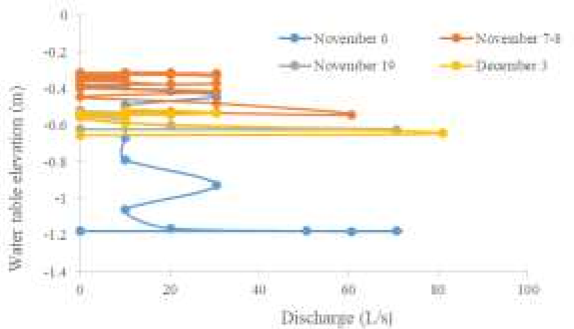

Fig 9. Graph of discharge vs water table elevation in Bagan Melibur Village .

4. Conclusions

Research on Pulau Padang peatlands shows that there are significant changes in groundwater levels during the period of data collection. Those are secondary data from 2015 to 2017 and primary data comes from November to December 2017. There are major differences between an area with the systematic channel and the area with no systematic channels. The area with the systematic channel has an opportunity to arrange the water elevation at the canal to control water elevation, in order to control water table elevation. Different from the situation, the area without the complete channel will be determined by the season and the environment. Any further research about the relationship between the canal, its dimension, and density to the water table elevation is needed to be developed.

Changes in water level are mainly determined by the rain and the condition of initial water level at certain altitude that exceeds the standard from the Government's Regulation, which is -0.4 m. There are similarities and differences in the two locations of study. The hydrological response in the two regions, especially the flow rate in the channel, looks the same. Moreover, in Sei Hiu Village, there is no previous condition (antecedent) with a significant water table level. Further research is needed on the different states in the dry season because there is evaporation and it has an impact to the influence of thick peat in changing the land surface and response of flow.

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