Water table depth fluctuations during ENSO phenomenon on different tropical peat swamp forest land covers in Katingan, Indonesia

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Abstract. As it is the main role to maintain hydrological function, peatland has been a limelight since drainage construction for agriculture evolved. Drainage construction will decrease water table depth (WTD) and result in CO₂ emission release to the atmosphere. Regardless of human intervention, WTD fluctuations can be affected by seasonal climate and climate variability, foremost El Niño Southern Oscillation (ENSO). This study aims to determine the correlation between rainfall in Katingan and ENSO index, analyze the pattern of WTD fluctuation of open area and forest area in 2015 (during very strong El Niño) and 2016 (during weak La Niña), calculate the WTD trendline slope during the dry season, and rainfall and WTD correlation. The result showed that open area has a sharper slope of decreasing or increasing WTD when entering the dry, compared to the forest area. Also, it is found that very strong El Niño in 2015 generated a pattern of more extreme decreasing WTD during the dry season than weak La Niña in 2016.

1. Introduction
Peatland is a unique ecosystem with high carbon stock that functions to maintain the hydrological condition in the surrounding areas. Disturbance to peatland ecosystem can alter its function from storing to emitting carbon. Based on the Biennial Update Report Republic of Indonesia, Land Use Change and Forestry (LUCF) sector contributes more than a half of national emission in the period 2000 – 2012, with the highest contribution, is from peat decomposition (45.5%) [1]. Emission from peat decomposition is allegedly sourced from drained peatland area with drainage construction for plantation activity purposes. Regardless of drainage and human intervention, fluctuation of water table depth (WTD) in peatland can be affected by seasonal and climate variability, foremost El Niño Southern Oscillation (ENSO). ENSO is a wide scale atmospheric-oceanic phenomenon cycled for 3 – 7 years in Equatorial Pacific [2]. ENSO occurrence will affect the onset and length of the dry season and rainy season, which will generate a different pattern of WTD in each El Niño and La Niña year [3]. However, though will not continuously occur, there is a possibility that ENSO amplitude will change in the future due to climate change. Therefore, it is necessary to analyze WTD fluctuation during ENSO, its trendline slope on the dry season, and its correlation with rainfall changes.
2. Data and method

The historical rainfall data used in the present study are 30 years daily precipitation of Climate Hazard Group Infra-Red Precipitation with Station (CHIRPS) 1987 – 2017 with 5 km x 5 km spatial resolution, validated using available daily observation data of H. Asan Sampit weather station (located in the latitude of -2.55° and longitude of 112.93°). CHIRPS daily grid precipitation data was extracted using Ocean Data View (ODV) software and validated using Microsoft Excel and Minitab software. Monthly sea surface temperature (SST) anomaly of NINO 3.4 from 1987 – 2017 used in this study were obtained from NOAA.

Determination of the onset of the dry season and rainy season in this study is based on the assumption of Indonesia’s Bureau of Meteorology and Climatology of 10 days (known as dasarian) precipitation. The meteorological condition of equatorial Pacific Ocean visualized by Grid Analysis and Display System (GrADS) version 2.0.a9.oga.1, using data of 1000 m.bar zonal and meridional wind and SST were obtained from European Center for Medium-Range Weather Forecast (ECMWF) from January 2015 to January 2017.

Daily WTD were generated from hydrology monitoring activities in the study area from February 2015 to January 2017. Our study site in Katingan District, Central Kalimantan, Indonesia, covers 149.800 ha project area of PT Rimba Makmur Utama that is flanked by two main watersheds (figure 1). WTD in the project area is monitored in 3 transects, transect A that represents the open area, and transect D and I that represent forest land cover. The sequence of monitoring point of transect A from the nearest to farthest from canal are A1, A2, and A3. The sequence of monitoring point of transect D from the nearest to farthest from the open area are D1, D2, D3, and D4, whilst for transect I, from the nearest to farthest from canal are I1, I2, I3, and I4. Missing values of WTD were corrected using weighted interpolation method, and only the most complete data during the 2 years monitoring period were used for seasonal and correlation analysis (I1 and I3 were excluded from this analysis).

3. Result and Discussion

ENSO and rainfall variability in the study area is proved that SST anomaly of NINO 3.4 zone (170°W-120°W and 5°N-5°S) has a stronger correlation with monthly anomaly precipitation in Indonesia if compared to another zone [4]. High correlations of rainfall index (1987 – 2017) and SST NINO 3.4 anomaly were showed in July – November, where the highest correlation was -0.744, in September.
Period of July – November showed the most significant correlation with a p-value less than 0.1. Based on the historical data of SST NINO 3.4 anomaly and monthly rainfall in the study area, the positive value of SST NINO 3.4 anomaly always followed by the decrease of rainfall, while the opposite during negative value of SST NINO 3.4 (figure 2b).

**Figure 2.** (a) Correlation of monthly rainfall index in the study area and monthly SST NINO 3.4 anomaly (b) Monthly rainfall in the study area and monthly SST NINO 3.4 anomaly Jan 1987 – April 2017.

In the year of 2015, very strong El Niño occurred with the highest SST anomaly in zone NINO 3.4 reached 2.95°C on November 2015, while in the year of 2016, weak La Niña occurred with the lowest SST anomaly in zone NINO 3.4 reached -0.73°C on October 2016. El Niño in 2015 started in February-March-April (FMA) 2015 and ended in April-May-June (AMJ) 2016, whilst La Niña in 2016 started directly a few months later and ended in November-December-January (NDJ) 2016 (figure 3). El Niño to La Niña transitions usually occurs much faster than La Niña to El Niño where almost all El Niño to La Niña transitions occur within one year [5].

Besides the strong influence of rainfall variability in Indonesia, ENSO events also influence interannual rainfall variability in Indonesia. End of the dry season tends to occur later than normal during El Niño and earlier than normal during La Niña years, and the onset of the wet season is delayed during El Niño and advanced during La Niña years [6]. Based on the result of precipitation analysis year 2015 and 2016, the onset of the dry season in 2015 occurred earlier in the 3rd 10 days of June, compared to 2016 that occurred later in the 1st 10 days of August. On the contrary, the onset of the rainy season in 2015 moved backward in the 3rd 10 days October, while in 2016 moved forward in the 2nd 10 days of September. Moreover, it was found that dry spell in 2015 occurred longer than in 2016, with the value 21 and 8, respectively. A wet spell in 2015 on the other hands, occurred shorter than in 2016, with value 24 and 40, respectively.
Figure 3. Development of SST anomaly (°C) in equatorial Pacific (5°N – 5°S) on January 2015 – January 2017 along 60°E - 80°W, straight line showed the boundary of Indian Ocean (IO), West Pacific (WP), Central Pacific (CP), and East Pacific (EP). (Graph generated from ECMWF data using GrADS).

Water table depth fluctuation as shown in figure 4a, water table depth in A3 was logged only during the rainy season and almost never logged in A1 and A2. As shown in figure 4b, there was a clear difference of the maximum, minimum, and average value of WTD in 2015 and 2016. Minimum water table depth in transect A always on the below ground and reached -2 m on October 2015 (average -1.5 m), while in September 2016 only reached -1.2 m (average -0.6 m). Meanwhile, based on the graph of maximum WTD, it is shown that on 2015 water table were logged for 2 months, while on 2016 water table were logged for 6 months. But on average condition, water table depth in transect A was never logged neither on dry season nor rainy season.

Figure 4. Graph of WTD in Open Area (a) Daily Fluctuation (b) Monthly min, max, and average.

Variations of water table depth fluctuations of each monitoring point in transect A are more affected by the elevation rather than its position towards the canal. Based on the slope data collected from the field, the low slope of A3 to A2 result in slow water flow from A3 to A2. Meanwhile, the high slope of A2 to A1 result in high water flow from A2 to A1 that makes water table depth in A2 become low. The close distance from A1 towards the canal could interfere water table in A1 by
holding up outflow from open area to the canal. As a result, water flow from A2 and A3 accumulated in A1 and leads to a high water table depth in A1.

As shown in figure 5a, water table depth in transect D was logged during the rainy season and partially on dry season, except in D1. Based on figure 5b, there was a difference of the minimum, maximum, and average value of WTD transect D in 2015 and 2016, especially during dry season. Moreover, it is shown that in 2015 water table were always logged except in September and October where El Niño developed became stronger as sea surface temperature of NINO 3.4 increase approximately 2.46°C.

Figure 5. Graph of WTD in Forest Area (a) Daily Fluctuation of Transect D, (b) Monthly min, max, and the average of Transect D, (c) Daily Fluctuation of Transect I, and (d) Monthly min, max, and the average of Transect I.

WTD on transect D in 2016 were logged longer than 2015 due to the longer occurrence of the dry season in 2015 than 2016. As ENSO phenomenon affect the length of the dry season and the rainy season, it will also affect the length of water table depth was logged in transect D. According to another study, the lowest value of WTD also depends on the length of dry spell [7]. WTDs in point D1 were considerably lower than those in D2, D3 and D4, likely caused by its closer proximity to open area. Therefore, it is likely that point D1 tend to represent WTD fluctuations in forest edge rather than forest area, showing a wide gap between monitoring points inside forest areas (D2, D3, D4) that are relatively similar to each other (figure 5a).
Based on figure 5c, WTD in transect I were logged for a while during the rainy season and decreased on the below ground during the dry season. According to figure 5d, there was less difference on minimum, maximum, and average value of WTD Transect I in 2015 and 2016, showing that ENSO occurrence was less apparent on WTD fluctuation in transect I. In the year of 2016, WTD decrease sooner than 2015 and based on the WTD data on 2016, it is also shown that transect I has earlier downturn point before the onset of the dry season. However, the lowest WTD in transect I was not as low as transect D, showing that WTD fluctuation in transect I tend to be more stable than transect D (not too dry, not too wet), which is explained by the location of transect I on the upstream position, near to Klaru river (figure 1).

Based on the data obtained, lowest WTD always occurs at the end of dry season, and if compared to two different ENSO occurrences, lowest WTD during the dry season in 2015 was lower than during dry season in 2016. Hence, the difference of lowest minimum WTD in two different ENSO phenomena will result in additional emission decomposition [8]. As WTD in each transect is also affected by elevation and its location towards the canal or open area, it is too soon to conclude that type of land cover affected the value of water table depth in general, but certainly land cover could affect the difference between highest and lowest value of WTD. However, based on the other study, when comparing site factors, bare peatland consistently emits higher CO2 than under forested land [9].

Seasonal analysis of water table depth’s decrease during the dry season (figure 6a, b) is observed from the onset of the dry season until the end of dry season. Based on the result in figure 6, transect A tends to have steeper trend than transect D and I, while transect I tend to has slightly trend than transect D (Table 1). Regardless of its water table depth, the types of land cover are more affected in the trend line slope of water table depth decrease, where it can be seen a clearly different value of slope in the different type of land cover (Table 1). Trendline slope can describe the characteristic of each land cover, especially its capability to maintain and play its hydrological function. The slighter the slope, the better water storage condition.

| Monitoring point | Trendline Slope |
|------------------|-----------------|
|                  | A1  | A2  | A3  | D1  | D2  | D3  | D4  | I2  | I4  |
| Dry Season 2015  | -1.07 | -1.11 | -0.89 | -0.92 | -0.89 | -0.82 | -0.75 | -0.75 | -0.79 |
| Dry Season 2016  | -0.15 | -0.95 | -0.80 | -0.72 | -0.70 | -0.73 | -0.80 | -0.59 | -0.48 |

Based on the different year of seasonal analysis, the decrease water table depth on the dry season 2015 was steeper than dry season 2016. The trend of WTD during the dry season in 2016 quite similar in transect A and D (Table 1). It is estimated that the smallest trend in transect A shown in monitoring point A1 is caused by an interfering from the canal. The lowest trend during dry season 2016 results in transect I.

Rainfall and water table depth correlation Cross-correlation is used to analyze the time-lagged relationship between rainfall and WTD and assess the sensitivity and responsiveness of water table fluctuation to the rainfall change, described by the highest value of cross-correlation (CC) [10]. The highest value of CC occurred on the varied lag time of all monitoring point (Figure 7). Highest CC in A1, A2, and A3 occurred on the lag time 35, 30, and 23 respectively. Later lag time in A1 and A2 than A3 expected caused by its close distance to the canal. Highest CC of all monitoring point of transect D occurred on the lag 24, except D2 that occur on the lag 30, meanwhile transect I have the longest lag time, where both I2 and I4 have lag time 32 and 35. Based on the other study, the lag of water table changes due to addition or reduction of rainfall occurs a month [11].
Figure 6. Water Table Depth (a) Decrease during dry season 2015 (b) Decrease during dry season 2016.

Based on the regression equation (figure 8), the value of slope showed how changes in addition or reduction of 10 days rainfall affect the changes of average 10 days water table depth in the lag time (t+30). Even though transect A and D have quite similar time lag (ignoring the interfere from a canal in A1 and A2), the slope of WTD changes due to additional and reduction of rainfall is different. Based on its land cover, transect A has a higher value of slope than transect D and I. Therefore, transect A will experience the highest change of WTD due to any change (addition or reduction) of rainfall compared to others transect. Meanwhile, the lowest value of slope measured in transect I that indicated the water table in transect I tend to be more stable than another transect.

Based on the other study Qalbi [12], the result of projected future sea surface temperature anomaly by four model Global Climate Model Couple Model Intercomparison Project phase 5 (GCM CMIP5) that has a different condition of SST anomaly in each of the model, generally showed that ENSO phenomena in period 2006 – 2035 is estimated to be more intensive and strong with SST anomaly that can reach up to approximately 4°C. Based on the result of the scenario of occurrence single El Niño event, it is predicted that monthly rainfall will decrease 50 – 100 mm/month in Central Kalimantan if compared to rainfall variability in period 1981 – 2010 [12].
4. Summary and concluding remarks

The highest and most significant correlation of SST NINO 3.4 anomaly and rainfall index in the study area occurred during the period of July – November. ENSO occurrence evidently affected the onset and length of the dry season and rainy season, which will generate a different pattern of WTD in each El Niño and La Niña year. ENSO occurrence will also affect the trendline of water table fluctuation during the dry season and wet season, where its trendline during the dry season in El Niño year was more abrupt compared to La Nina year. However, regardless of the land cover, there are other factors that affect the variation of WTD in each transect such as elevation and distance towards the canal. A land cover factor tends to influence more on the difference of maximum and minimum WTD, trend line slope of WTD during the dry season, and the slope of regression that describes changes of WTD to the rainfall change. The impact of land cover on lag time remains conjectural due to the interference factor from the nearest canal, particularly in transect A. ENSO occurrence clearly affects water table depth fluctuation and contributes to an additional emission of peat decomposition. Thus, with the possibility that ENSO amplitude will change in the future due to climate change, there should be an attempt to increase WTD by rewetting to mitigate the GHG emission on degraded peatland especially when ENSO occurs.

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