Water Balance of Various Peatland Typologies in Central Kalimantan

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Abstract. The water balance of a peatland area is important information for the management of water resources. This study aims to predict the water balance in several typologies of peatlands in Central Kalimantan, Indonesia. The method used is a Thornthwaite Mather water balance analysis model. This method is based on input data in monthly rainfall and temperature in 2019 at the study locations. The output of this method is predicted monthly runoff. The method analyzes the evapotranspiration process and the soil's ability to hold water. There are four types of peatlands analyzed: (1) primary forest (Mangkok), (2) secondary forest (Forest Area with Special Purpose/FASP Tumbang Nusa), (3) Shrubs (RePeat), and (4) open area. Research results show that the annual rainfall in Mangkok is 2,555 mm/year, with the actual evapotranspiration of 1,594 mm/year, yield the annual water of 653 mm/year. In the FASP Tumbang Nusa, the annual rainfall is 2,570 mm/year, with the actual evapotranspiration of 1,592 mm/year, yield the annual water of 648 mm/year. In the RePeat location, the annual rainfall is 2,550 mm/year, with the actual evapotranspiration of 1,580 mm/year, yield the annual water of 549 mm/year. The open area location (Kahayan) has an annual rainfall input of 2,375 mm/year, then the actual evapotranspiration is 1,598.98 mm/year, while the annual water yield is 823.08 mm/year. The water deficit in the four study locations occurred from July to September, while the water surplus occurred from January to June and continued from October to December. August to November is the month with the lowest water yield in the four study locations.

1. Introduction
Southeast Asia's peatlands cover roughly 24.8 million ha, or 56 percent of the world's tropical peatland [1], including approximately 11 million ha in Borneo [2]. The lowland peatlands of Borneo, especially those in Central Kalimantan, are exclusively rain-fed and are flooded throughout the year in natural conditions [3]. This peatland has hydrological and environmental functions for the life and livelihood of humans and other living things, so it must be protected and preserved [4]. Peat swampland ecosystems are unique ecosystems that have a critical role from an economic, ecological, and social perspective. Some of the critical roles of peatland include environmental support, agricultural land, a source of water reserves, a habitat for particular flora and fauna that are adaptive to peatland, rice production locations, and others [5, 6]. Peatlands also play an essential role in controlling the global climate because they can absorb and store carbon [5].

Tropical peatlands are naturally wooded, but nearly 60% of Sumatra and Borneo's peat swamps have been deforested in the last 30 years [7,8]. Some of this land has been deteriorated and unproductive,
while roughly half of the total peatland is now managed as a plantation, either for agriculture (primarily oil palm) or wood fiber production. This shift from natural forest to plantation has aided regional economic development and currently employs many people. Peatland subsidence is one of the negative effects of this change [9]. Oxidation is responsible for 60% of peat sinking, while irreversible drying or shrinking is responsible for 40% [10]. Because subsidence is inversely proportional to drainage depth, different land-use types result in significant but variable carbon emissions due to their associated ideal water levels [11].

Understanding and managing the water balance are essential for long-term land development in tropical peatlands and efficient soil and animal conservation. Tropical peatlands in Indonesia and Malaysia are frequently characterized by high rainfall projections that surpass evapotranspiration capability [12]. Because the infiltration capacity of peat soils and transmissivity does not allow for the disposal of all excess precipitation, significant quantities of water are released by surface runoff (including interflow) and surface watercourses. Only a small portion of the additional rainfall recharges the groundwater. The groundwater regime of a peatland is influenced by the groundwater recharge pattern, geometry, and hydraulic characteristics of the soils. Any land development can alter the groundwater regime, resulting in various downstream effects such as soil subsidence and ecosystem deterioration [12]. The groundwater system must be analyzed and evaluated in each peatland development or conservation scenario.

Currently, a large range of groundwater models is accessible. MODFLOW and SIMGRO, two groundwater modeling software, are being used in current research on peatlands in Malaysia and Indonesia [12]. However, these models require many data with long time series. Peatland Restoration Agency (BRG) has proposed a model usually used in the mineral soil to be used in the peatland, namely the Thornthwaite-Mather (TM) model. This model requires relatively less data, while the data are easy to be collected. The Thornthwaite-Mather water balance method has been widely used to calculate water balance [13] and provides reasonably accurate water balance estimation results [14,15]. In their research in India, Khandelwal and Pandey [14] found that the TM method can accurately predict the value of potential evapotranspiration (PET) at almost all observation stations. Meanwhile, Pramono and Adi [15] found that the results of the water balance estimation using the TM method gave results that were not significantly different from the measurement results. Many studies have used this TM method in predicting the water balance of watersheds in Indonesia, including Murtiono [16] in several catchment area of reservoirs, Gajah Mungkur, Peranginangin, Sakthivadivel, Scott, Kendy and Steenhuis [17] in Singkarak, Fu'adah, Iryanti and Mujahiddin [18] in Bandung, Samsoeedin, Heriyanto and Subiandono [19] in Carita, Banten, and Kafindo [20] in Ponorogo. Some studies also used the TM model for predicting the water balance in the peatland area [21]. This study aims to estimate the water balance in some peatland typologies in Central Kalimantan, Indonesia.

2. Methods

2.1. Materials and equipment

Materials and equipment needed in this study are basic maps (i.e., DEM, soil type, land cover, peat depth, canal networks), climatological data (rain and temperature) of the study location and its surroundings, soil survey equipment, GPS, and data processing software (spreadsheet), as well as ArcGIS.

2.2. Data collection and analysis

The method used in this study is the water balance of the Thornthwaite & Mather method, with the rainfall as the input, whereas surface runoff and evapotranspiration as the outputs. The ability of the soil to hold water, including land cover, is an input to output process in the unit of analysis. Before doing the calculation, the first step is determining the hydrological response unit analysis by overlaying some maps: DEM, peat depth, and canal network.
In calculating the water balance using the Thornthwaite Mather method [22], some of the data is needed, i.e., monthly average temperature, monthly average rainfall, \( pF 2.54 \) and \( pF 4.2 \) values, and depth of the plant root zone [23]. The final result of the calculation of the water balance is in the form of a predicted total runoff for one year at the study location, which is identical to the prediction of the water potential of the study location.

We follow the data analysis steps described by Dourado-Neto, van Lier, Metselaar, Reichardt and Nielsen [24] and Pramono and Adi [15]. Generally, the water balance of an area of forest or vegetated land is:

\[
P = Q + E \pm \Delta S
\]

where \( P \) represents rainfall, \( Q \) is discharge, and \( E \) represents evapotranspiration. \( \Delta S \) denotes the changes in soil moisture content.

The monthly water potential in the study location is calculated as follows. First, the calculation of rainfall data for the average monthly occurrence in the study locations was carried out using the Thiessen polygon method. Second, soil analysis was conducted to determine the value of the soil's water-holding capacity (WHC). Third, the calculation of evapotranspiration is carried out using the following equation:

\[
PE_m = 16 \left(10^T\right)^a
\]

\[
l = \sum_{i=1}^{12} \left(\frac{T_i}{5}\right)^{1.514}
\]

\[
α = 0.000000675l^3 - 0.0000771l^2 + 0.01792l + 0.49239
\]

Where: \( PE_m \) is the uncorrected potential evapotranspiration, \( T \) is the monthly average temperature (in degrees Celsius) and \( l \) is the annual heat index.

To find out the corrected potential evapotranspiration value, the value \( PE_m \) must be corrected using a correction factor \( f_m \), i.e., \( f_m = 1/360(h_mN_m) \) where \( f_m \) is the correction factor for evapotranspiration for the month \( m \), \( h_m \) is the length of the average sun irradiation every day in the month \( m \) and \( N_m \) is the number of days in each month in each month. The value of the evapotranspiration correction factor based on latitude has been calculated by Nugroho [25]. The corrected evapotranspiration value is \( PE = PE_mf_m \). To determine the value of soil moisture, it is necessary to know the WHC value based on the soil analysis carried out, following the equation:

\[
SM = WHC \times e^{\frac{APWL}{WHC}}
\]

Forth, the amount of water runoff or runoff is calculated under several conditions:

a) when \( P > PE, AE = PE \) (6)

b) If \( P < PE \), then some conditions can apply to \( E = PE = P + \text{the SM part} \) (7)

c) If SM does not represent a sufficient amount of groundwater moisture, then:

\( AE < PE \) where is \( AE = P + \text{the remainder of SM} \) (8)

From the total monthly runoff, 40-60% will run off in the following month.

3. Results and discussion

3.1. Determination of the water balance analysis unit

The first step in calculating the area's water balance is determining the unit of analysis called the Hydrological Response Units (HRU). The hydrological response analysis unit is made by overlaying several maps, namely DEMNas (Digital Elevation Model) map, peat depth map, and canal network map.
at the study location. The results of the hydrological response analysis unit at the study location are presented in Figure 1.

![Figure 1](image1)

**Figure 1.** Study locations: (a) Mangkok resort, (b) secondary forest, (c) RePEat, (d) open area

### 3.2. Land cover at the study site

Land cover analysis in the four study locations was carried out using GIS tools. The source of the map sheet for land cover analysis is the 1: 250,000 scale Land Cover Map from the Directorate General of Forestry Planning and Environmental Management in 2019. Because the map scale is very global, there are locations where the land cover conditions on the map do not match the actual conditions in the field. Therefore, it is necessary to make adjustments using direct surveys at the study location. The results of land cover analysis at the study location are presented in Figure 2.

Figure 2 shows that there is not much variation in land cover in the study location. However, the dominance of land cover in the four locations is not the same. The land cover conditions in the Mangkok location and the natural succession scrub (RePEat) location were all swamp shrub. However, the plant density in the two locations was not the same. For the Mangkok location, the land cover was much denser than the natural succession scrub (RePEat) location (Figure 2c). In the RePEat area, many peatland fires occurred in 2015 (Figure 2c). Then for secondary forest locations and open land (Kahayan) locations, the actual land cover conditions in the field are not following the land cover map classification from the Director-General of PKTL. The actual conditions of the open area (Kahayan) are shrubs (Figure 2d), while those in secondary forest locations are currently closed with several types of dense stands.
3.3. Water balance of several typologies of peatlands in Central Kalimantan

Water balance calculations in several peatland typologies were carried out using the Thornthwaite Mather method approach. Based on several studies, this method is quite valid because it has a high correlation when compared with direct measurements. Comparing the predicted results of monthly runoff using the Thornthwaite Mather method with direct measurements has an $R^2$ value ranging from 0.7 to 0.9 [26]. This method uses input temperature data and rain data. The temperature data used for calculating the water balance of several peatland typologies is data from the climatology station of Tjilik Riwut Airport, which is extrapolated based on the difference in altitude between the airport and each study location. Table 1 shows that the highest temperature at the study location occurred in May and when compared between the four study locations, the one with the highest temperature in May was Mangkok location. Then the lowest temperature occurred in January, and among the four lowest temperatures was the location of RePeat natural shrubs. Furthermore, for rainfall data, because the study location and its surroundings do not have routine rain monitoring, the rainfall data used for analysis uses rainfall data from satellite analysis (CHIRPS). The consideration used to utilize the CHIRPS data is to compare the direct observation data at Tjilik Riwut airport with data from the analysis results from the satellite. Around the location of the rainfall prediction study using CHIRPS, it is closer to the rain data from direct monitoring at the BMKG station at Tjilik Riwut airport. Meanwhile, the prediction of rainfall using TRMM is too low (underestimate). Table 1 also shows that the highest rainfall occurs in December, with the highest rainfall falling at the Mangkok location, while the lowest rainfall occurs in September, with the lowest rainfall occurring in the Natural Scrub and open locations (Kahayan). In general, the rainfall fell throughout the year in 2019; therefore, 2019 can be a wet year because it always rains every month. Other data related to the calculation of the water balance is the value of $p_{F}$. 

Figure 2. Land cover in the study location: (a) Mangkok resort, (b) secondary forest, (c) RePeat, (d) open area
because this time the soil samples are still unfinished analyzed then the value of water storage (Storage) using the reference dar similar research conducted by BRG 2019 at KHG Pulau Tebing Tinggi, Meranti Islands, Riau Province. The water-saving value in question is 140 mm/month [21]. The amount of monthly runoff that occurred was 40%, and the remaining 60% would be saved and released by 40% in the following month [21]. The results of the water balance analysis at the study location in 2019 are presented in Table 1.

**Table 1.** Results of water balance analysis of Mangok resort, open area, RePeat, and secondary forest in 2019

| Parameter          | Location      | Jan | Feb | Mar | Apr | May | Jun | Jul | Agt | Sep | Oct | Nov | Dec | Total |
|--------------------|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|
| Temperature (Celcius) | Mangok  | 27  | 27  | 27  | 27  | 27  | 27  | 27  | 27  | 28  | 28  | 28  | 28  | 28    |
|                    | Open area    | 26  | 27  | 27  | 27  | 27  | 27  | 27  | 27  | 28  | 28  | 28  | 28  | 27    |
|                    | RePeat       | 26  | 27  | 27  | 27  | 27  | 27  | 27  | 27  | 28  | 28  | 28  | 28  | 27    |
| Secondary forest   | Mangok       | 27  | 27  | 27  | 27  | 27  | 27  | 27  | 27  | 28  | 28  | 28  | 28  | 27    |
|                    | Open area    | 291 | 266 | 292 | 305 | 181 | 177 | 47  | 92  | 30  | 195 | 201 | 298  | 2375  |
|                    | RePeat       | 347 | 296 | 304 | 305 | 181 | 177 | 47  | 92  | 30  | 195 | 201 | 374  | 2550  |
| Secondary forest   | Mangok       | 335 | 300 | 314 | 310 | 182 | 186 | 48  | 83  | 31  | 200 | 207 | 375  | 2570  |
|                   | Open area    | 291 | 266 | 292 | 305 | 181 | 177 | 47  | 92  | 30  | 195 | 201 | 298  | 2375  |
|                   | RePeat       | 347 | 296 | 304 | 305 | 181 | 177 | 47  | 92  | 30  | 195 | 201 | 374  | 2550  |
| Secondary forest   | Mangok       | 140 | 133 | 144 | 145 | 153 | 145 | 115 | 105 | 56  | 153 | 155 | 150  | 1594  |
|                   | Open area    | 142 | 130 | 144 | 142 | 145 | 141 | 150 | 107 | 45  | 153 | 153 | 148  | 1599  |
|                   | RePeat       | 139 | 130 | 144 | 142 | 148 | 141 | 115 | 113 | 57  | 150 | 153 | 148  | 1580  |
| Secondary forest   | Mangok       | 142 | 133 | 144 | 142 | 151 | 144 | 115 | 108 | 57  | 153 | 153 | 151  | 1592  |
|                   | Open area    | 149 | 137 | 148 | 163 | 36  | 36  | 6   | -37 | -101| -91 | 48  | 150  | 645   |
|                   | RePeat       | 209 | 166 | 161 | 163 | 33  | 36  | -28 | -30 | -89 | -71 | 48  | 226  | 823   |
| Secondary forest   | Mangok       | 192 | 203 | 152 | 189 | 20  | 17  | -31 | -41 | -89 | -95 | 40  | 241  | 799   |
|                   | Open area    | 149 | 137 | 148 | 163 | 36  | 36  | 6   | -37 | -101| -91 | 48  | 150  | 645   |
|                   | RePeat       | 209 | 166 | 161 | 163 | 33  | 36  | -28 | -30 | -89 | -71 | 48  | 226  | 823   |
| Secondary forest   | Mangok       | 194 | 168 | 171 | 168 | 31  | 42  | -29 | -39 | -89 | -72 | 54  | 224  | 822   |
|                   | Open area    | 149 | 137 | 148 | 163 | 36  | 36  | 6   | -37 | -101| -91 | 48  | 150  | 645   |
|                   | RePeat       | 209 | 166 | 161 | 163 | 33  | 36  | -28 | -30 | -89 | -71 | 48  | 226  | 823   |
| Secondary forest   | Mangok       | 94  | 114 | 127 | 112 | 120 | 56  | 29  | 1   | -17 | -42 | -55 | -6   | 533   |
|                   | Open area    | 72  | 118 | 129 | 141 | 154 | 83  | 55  | 26  | 10  | 4   | 2   | 29   | 823   |
|                   | RePeat       | 91  | 120 | 115 | 110 | 109 | 57  | 37  | 4   | -11 | -40 | -44 | 1    | 549   |
| Secondary forest   | Mangok       | 91  | 114 | 113 | 113 | 112 | 57  | 40  | 4   | -14 | -41 | -45 | 4    | 548   |

Based on the water balance analysis in the study locations, the average water deficit starts in July and ends in October; only in the open area location, the water deficit starts in August. Meanwhile, the peak of the water deficit occurs in September, only in Mangok, where the peak of the water deficit occurs in October. Thus, around September and October, the study's location is prone to peat fires. However, it would be even more valid to determine the condition of peatlands prone to land fires if it is equipped with data on groundwater level fluctuations. Unfortunately, in this study, data on groundwater
level fluctuations in the four study locations were not yet available because new observations began in early November 2020, so that it could not strengthen the statement that around September and October, the groundwater level was deeper than 40 cm (peatland water level threshold according to the provisions). Furthermore, in Figure 3, three water balance parameters are presented in the four study locations.

![Figure 3. Parameters of the water balance of the study location](image)

Figure 3 shows that in the open area location (Kahayan), the lowest annual rainfall input is 2,375 mm/year, while in the other 3 locations (Mangkok, RePeat, and secondary forest), the rainfall input is almost the same, which is around 2,500 mm/year. Then for the actual annual evapotranspiration parameter, the highest value occurred in the open area (1,599 mm/year). Evapotranspiration is a combination of evaporation and transpiration [27]. Evaporation occurs on the land surface, and transpiration occurs on the surface of the plant leaves. The evapotranspiration proportion in our study is between 62-67% of the precipitation. Thus the conditions that occur in open area locations may be due to the influence of the high evaporation value because the conditions in this location are indeed very open. This is in line with the findings from Sarminah, Pasaribu and Ivanhoe Aipassa [28], where the evapotranspiration in the open area is higher than that in agroforestry. Depends on the type of vegetation, a research result in the Canadian peat shows that vascular plants can contribute up to 80% of ET [29]. Furthermore, the lowest evapotranspiration value location was the RePeat location (i.e., 1,580 mm/year). This is possible because the condition of the land is more covered with shrubs, but the conditions of the plants are not as close to the location of Mangkok and secondary forest, which causes low evaporation and transpiration because the dominant land cover is shrubs with small leaf widths. It is different from that in the Mangkok and the secondary forest locations, wherein the evapotranspiration value is higher than the RePeat location (but still lower than the open area). This is possible because of the high transpiration value in both locations because there are many stands with the condition that the leaf width is greater than the shrubs. Furthermore, if we look at the annual water yield parameters, the open area (Kahayan) location has the largest water yield value, which is 823 mm/year. Then, respectively after that are the Mangkok and secondary forest location, which has the exact annual water yield, namely 653 and 648 mm/year and the lowest annual water yield is the RePeat, which is 549 mm/year. The relationship between rainfall and runoff is presented in the four study locations is presented in Figure 4.
Figure 4. Relationship between rainfall and runoff at the study sites

Figure 4 shows that the rainfall in the study location from January to December did not necessarily cause an increase in runoff. The increase in runoff only occurred in the following month of a wet month. Based on the reference used to calculate the water balance of the study location at 40%, 60% of the rainfall that falls in the study location will be stored in peatlands, and 40% will be released as runoff. The 60% runoff stored in peatlands will be released as runoff in the following month, and the amount is the same at 40%. This is in line with the research finding using radar that the streamflow/runoff in the peatland area is between 10-50% of the precipitation [30]. Figure 4 shows that in the land covered by vegetation (i.e., Mangkok resort), the evaporation is higher than in the open area, and therefore the annual runoff is lower than in the open area. Based on Figure 4, it can also be seen that the largest average runoff occurred in May, and of the four study locations that had the largest runoff was the open area (Kahayan). After May, the runoff conditions decreased along with reduced rainfall in the four study locations, and even in three locations, namely Mangkok, natural succession scrub, and secondary forest, there was no runoff flowing from August to November. The new runoff will reappear in December when the rainy season starts to have a high intensity of rain.

The Thorntwaite-Mather water balance model has some drawbacks to be applied in the peatland, e.g., the model cannot estimate the groundwater recharge like the MODFLOW model. In the MODFLOW model, the groundwater recharge was 1.1% of the total precipitation [12].

Based on the 2019 water balance analysis results in the FASP Tumbang Nusa area, the conditions are not too bad because the water deficit is not too severe and can still be balanced by surplus conditions in the previous months. However, this still has to be watched out for because 2019 is a wet year where rainfall falls throughout the year in the four study locations. Even though the water deficit only occurred for three months (July - September) in 2019, it turned out that in the location of Mangkok, RePeat, and secondary forest, it caused low runoff and even no runoff at all until December. In this condition, peatlands tend to become dry, making them prone to land fires. A trigger that is sometimes only trivial will cause peatland fires even to spread if the peatlands are dry. Therefore, to prove that there is a water deficit or the peat soil water level is low or not, the GWL (groundwater level) condition must be seen. Currently, the GWL observations in the four study locations are still ongoing, but the GWL observation data is still very little so that it cannot be used in the current analysis.
4. Conclusions

Four types of peatlands in Central Kalimantan, i.e., primary forest (Mangkok), secondary forest (FASP Tumbang Nusa), shrubs (RePeat), and open area, are investigated for the water balance analysis. The annual rainfall in Mangkok is 2,555 mm/year, while the actual evapotranspiration is 1,594 mm/year, resulting in 653 mm/year of annual water. The annual rainfall in the FASP Tumbang Nusa is 2,570 mm/year, while the actual evapotranspiration is 1,592 mm/year, yielding 648 mm/year of annual water. The yearly rainfall in the RePeat area is 2,550 mm/year, and the actual evapotranspiration is 1,580 mm/year, yielding 549 mm/year of annual water. The yearly rainfall in the open area (Kahayan) is 2,375 mm/year, the actual evapotranspiration is 1,598.98 mm/year, and the annual water yield is 823.08 mm/year. The water shortage in the four research areas lasted from July to September, whereas the water surplus lasted from January to June and persisted through October and December. In all four study locations, August to November has the lowest water yield. The Thornthwaite Mather water balance model is a promising model for conducting the water balance in the peatland area.

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Author Contributions

All authors had an equal role as main contributors in discussing the conceptual ideas and the outline, providing critical feedback for each section, and writing the manuscript. All authors have read and agreed to the published version of the manuscript.

References

[1] Page S E, Rieley J O and Banks C J 2011 Global and regional importance of the tropical peatland carbon pool Global Change Biology 17 798-818
[2] Hooijer A, Page S, Canadell J G, Silvius M, Kwadijk J, Wösten H and Jauhiainen J 2009 Current and future CO2 emissions from drained peatlands in Southeast Asia Biogeosciences 2010 (2010) 7 7
[3] Ritzema H, Limin S, Kusin K, Jauhiainen J and Wösten H 2014 Canal blocking strategies for hydrological restoration of degraded tropical peatlands in Central Kalimantan, Indonesia CATENA 114 11-20
[4] Wahyunto, Ritung S, Suparto and Subagjo H 2005 Sebaran gambut dan kandungan karbon di Sumatera dan Kalimantan. Wetlands International
[5] Barus B and Iman L S 2009 Perbandingan Hasil Pemetaan Kesatuan Hidrologis dan Kubah Gambut dengan Citra Optik Landsat TM dan SAR. In: Semiloka Geomatika - SAR Nasional, (Bogor: LPPM - IPB, LAPAN, & BAKOSURTANAL) pp 187-94
[6] Rizaldi 2016 Perencanaaan lahan rawa untuk peningkatan produksi padi dan revisi tata ruang di Kawasan Hidrologis Gambut Muara Sabak Timur. (Bogor
[7] Miettinen J, Shi C and Liew S C 2016 Land cover distribution in the peatlands of Peninsular Malaysia, Sumatra and Borneo in 2015 with changes since 1990 Global Ecology and Conservation 6 67-78
[8] Wösten J H M, Clymans E, Page S E, Rieley J O and Limin S H 2008 Peat–water interrelationships in a tropical peatland ecosystem in Southeast Asia CATENA 73 212-24
[9] Evans C D, Williamson J M, Kacaribu F, Irawan D, Suardiverianto Y, Hidayat M F, Laurén A and Page S E 2019 Rates and spatial variability of peat subsidence in Acacia plantation and forest landscapes in Sumatra, Indonesia Geoderma 338 410-21
[10] Wösten J H M, Ismail A B and van Wijk A L M 1997 Peat subsidence and its practical implications: a case study in Malaysia Geoderma 78 25-36
[11] Wösten H and Ritzema H 2001 Land and water management options for peatland development in Sarawak, Malaysia International Peat Journal 11 59-66

9
[12] Ritzema H and Jansen H C 2008 Assessing the water balance of tropical Peatlands by using the inverse groundwater modelling approach

[13] Keim B D 2010 The lasting scientific impact of the Thornthwaite water-balance model Geographical Review 100 295-300

[14] Khandelwal M and Pandey V 2008 Comparison of PET computed by various methods in different agroclimatic stations of Gujarat state Journal of Agrometeorology 10 439-43

[15] Pramono I B and Adi R N 2010 Perbandingan hasil estimasi potensi air bulanan dan hasil pengukuran langsung di Sub DAS Wuryantoro, Wonogiri Jurnal Penelitian Hutan dan Konservasi Alam VII 127-37

[16] Murtizono U H 2009 Kajian ketersediaan air permukaan pada beberapa daerah aliran sungai (Studi Kasus di Sub DAS Temon, Wuryantoro, Alang, dan Keduang)

[17] Peranginangin N, Sakthivadivel R, Scott N R, Kendy E and Steenhuis T S 2004 Water accounting for conjunctive groundwater/surface water management: case of the Singkarak–Ombilin River basin, Indonesia Journal of Hydrology 292 1-22

[18] Fu’adah A T, Iryanti M and Mujtahiddin M I 2015 Analisis spasial ketersediaan air tanah di wilayah bandung dengan menggunakan metode neraca air Thornthwaite-Matter Fibusi (Jurnal Online Fisika) 3

[19] Samsoedin I, Heriyanto N and Subiandono E 2016 Struktur dan komposisi jenis tumbuhan hutan pamah di Kawasan Hutan dengan Tujuan Khusus (KHDTK) Carita, Provinsi Banten Jurnal Penelitian Hutan dan Konservasi Alam 7 139-48

[20] Kafindo A N 2015 Analisa kekeringan menggunakan metode Thornthwaite Mather pada Sub-Sub DAS Keyang Kabupaten Ponorogo. In: Fakultas Teknik, Universitas Brawijaya, (Malang: Universitas Brawijaya)

[21] Sutikno S 2019 Kajian hidrologi dan pengelolaan sumberdaya air pada KHG Pulau Tebing Tinggi, Kepulauan Meranti, Provinsi Riau. In: Laporan Final Kerja Sama BRG dengan Pusat Studi Bencana (PSB) – LPPM Universitas Riau dan Universitas Sriwijaya, (Pekanbaru: Universitas Riau-BRG)

[22] Thornthwaite C and Mather J 1957 Instruction and Tables for Computing Evapotranspiration and Water Balance

[23] Pramono I B and Adi R N 2001 Pedoman teknis perhitungan neraca air dengan metode Thornthwaite-Mather. (Surakarta: Balai Teknologi Pengelolaan DAS Surakarta)

[24] Dourado-Neto D, van Lier J, Metselaar K, Reichardt K and Nielsen D R 2010 General procedure to initialize the cyclic soil water balance by the Thornthwaite and Mather method Scientia Agricola 67 87-95

[25] Nugroho A 1989 Beberapa Teori Dan Aplikasi Rumus Thornthwaite Untuk Menghitung Jumlah Cadangan Sumberdaya Air= Some theories and application of the Thornthwaite formula to estimate water resource potential Majalah Geografi Indonesia 2

[26] Calvo J C 1986 An evaluation of Thornthwaite's water balance technique in predicting stream runoff in Costa Rica Hydrological Sciences Journal 31 51-60

[27] Ding R, Kang S, Zhang Y, Hao X, Tong L and Du T 2013 Partitioning evapotranspiration into soil evaporation and transpiration using a modified dual crop coefficient model in irrigated maize field with ground-mulching Agricultural Water Management 127 85-96

[28] Sarminah S, Pasaribu M and Ivanhoe Aipassa M 2019 Pendugaan evapotranspirasi di lahan agroforestri dan lahan terbuka hutan pendidikan Fakultas Kehutanan Unmnl AGRIFOR 18 325

[29] Whitfield P H, St-Hilaire A and van der Kamp G 2009 Improving Hydrological Predictions in Peatlands Canadian Water Resources Journal / Revue canadienne des ressources hydriques 34 467-78

[30] Holden J, Burt T P and Vilas M 2002 Application of ground-penetrating radar to the identification of subsurface piping in blanket peat Earth Surface Processes and Landforms 27 235-49