Thornthwaite and Mather water balance method in Indonesian Tropical Area

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Abstract. The Thornthwaite and Mather water balance method has been widely applied in the world, one of which is in Indonesia. However, almost all studies using the Thornthwaite and Mather water balance method in Indonesia are not validated. Considering that the Thornthwaite and Mather water balance study makes it easier to study hydrology, especially in areas that do not yet have complete and evenly distributed hydrological and meteorological stations. The research locations are in the Wampu sub-watershed, Serayu sub-watershed, Ayung sub-watershed, and Tondano sub-watershed. The method used is the Thornthwaite and Mather water balance with input data on rainfall, temperature, land use, latitude, and soil texture. The validation test was performed using the RMSE equation from the runoff model compared to the observation runoff (river discharge data). The RMSE results of the Thornthwaite and Mather water balance method in the Ayung sub-watershed (42.42%), Serayu sub-watershed (53.77) Wampu sub-watershed (65.58%) and Tondano sub-watershed (83.68%) were classified as weak correlation categories. The comparison results of the Thornthwaite method in tropical areas had greater rain, potential evapotranspiration, and runoff values than other climatic areas. Based on the result, we need to modify the Thornthwaite and Mather method for tropical areas and add a range of 25-30 years of climate data.

1. Introduction
The Thornthwaite and Mather water balance method has long been used and applied worldwide [1,2]. The Thornthwaite and Mather water balance method has included latitude parameters so that it can be applied in different climatic regions [3,4]. The Thornthwaite and Mather method provides an easy assessment of water balance in any region of the world [5], including regions that have zero water discharge data [6,7]. In addition, the Thornthwaite and Mather method can be used either within natural boundary areas in the form of watersheds [8,9] or within non-natural boundary areas [10,11]. The Thornthwaite and Mather method has been modified several times for more detailed and specific areas [12,13]. The Thornthwaite and Mather method modification was made due to the low accuracy of the original model and measurement, or some mismatches with existing local parameters.
The Thornthwaite and Mather method has been widely applied in Indonesia. There is a tendency that Thornthwaite and Mather water balance studies applied in Indonesia are mostly without any validation. Validation is very important in knowing the accuracy of the Thornthwaite and Mather method so that there are no errors in the analysis and calculation of further studies. Based on this, it is necessary for us to conduct research to validate the applications of the Thornthwaite and Mather method in Indonesia.

In Indonesia, the Thornthwaite and Mather water balance method is widely used by government agencies, academics, and privates for regional and development planning. Many regional and development plans are designed for areas that do not have hydrological measurement stations or in remote areas. Under this condition, the Thornthwaite and Mather method is very important because it is used for preliminary studies before conducting any further and more detailed studies. The preliminary studies are also an initial stage in selecting planning priorities in a region. Therefore, the validity of the Thornthwaite method results in tropical areas, especially in Indonesia, is crucial despite the fact that Indonesia still has a minimal distribution of hydrological stations, both for discharge and rain measurements. The Thornthwaite and Mather method is one of the keys in determining the priorities for initial planning related to hydrology.

Table 1. Study area.

| No | Watershed | Regency, Provinces | Mount | Watershed area (km²) |
|----|-----------|-------------------|-------|---------------------|
| 1  | Sub Serayu| Wonosobo, Central Java | Dieng Volcano and Sindoro | 136.82 |
| 2  | Sub Tondano | Minahasa, North Sulawesi | Tondano and Kabat | 140.41 |
| 3  | Sub Wampu | Langkat, North Sumatra | Sinabung and Volcano | 435.44 |
| 4  | Sub Ayung | Mambal, Bali | Agung Volcano | 275.55 |

The study locations are in Indonesia, spreading across several islands: Sumatra, Java, Bali, and Sulawesi (Table 1). Climatic conditions on sites. The study locations include tropical climates with annual rainfall ranging from 1000 to 4000 mm/year [14], humidity ranging from 60% to 80% [15], and temperatures ranging from 28 ° to 30 °C [16]. In addition, the study locations are strongly influenced by the western and eastern monsoonal winds [17]. The study locations are predominantly head-watered on active volcanoes and a small number of them are head-watered on old volcanoes. The dominant land uses in the study locations are in the form of forests and gardens in the upstream part; and settlements and rice fields in the downstream part. Elevational variations in the sub-watersheds in the study locations range from 500 to 2500 MASL (mean average sea level). The shape of the sub-watersheds in the study locations are elongated (Figure 1).

2. Methods

2.1. Water Balance Data

The data used for the water balance study include rainfall, temperature, latitude, land use, and soil texture. Rainfall and temperature data were obtained from the Meteorology, Climatology, and Geophysics Agency (BMKG) with a time span of 10 years (January 2006 - December 2018). Data on land use and latitude were obtained from the Spatial Information Agency (BIG). Soil texture data were obtained from the Ministry of Agriculture's Soil Research Institute. In addition, this research used secondary good discharge data as a validation of the water balance model. Secondary discharge data for the Ayung sub-watershed were obtained from (1993-2001) [18]; the Wampu sub-watershed was obtained from the Public Works Service of North Sumatra Province (2000-2015); the Tondano sub-
watershed was obtained from (1989-1993) [19], and Serayu sub-watershed was obtained from (1994-2004) [20].

2.2. Water Balance Calculation
The water balance was calculated using the method formulated by [21]. The first step was to calculate the potential evapotranspiration (Equation 1)

\[
PET_0 = 16 b_i (10^T_i) \alpha \quad \text{[mm/month]}
\]  

(1)

\(PET_0\) = potential evapotranspiration; 
\(b_i\) = radiation parameter for specific latitude; 
\(T_i\) = monthly air temperature; 
\(I\) = annual heat index (Equation 2) 
\(\alpha\) = complex function of heat index (Equation 3)

\[
I = \sum_{i=1}^{12} \left(\frac{T_i}{7}\right)^{1.514}
\]

(2)

\(T_i\) = monthly temperature 
\(\alpha = 6.75 \times 10^{-7}I^3 - 7.71 \times 10^{-5}I^2 + 1.7912 \times 10^{-2}I + 0.49239\)

(3)

The second step was to calculate the difference between \(P\) (precipitation) - PET. The result of \(P\)-PET reduction was used to calculate the APWL (accumulated potential water loss). If (P-PET) was positive (+), then APWL was 0. If (P-PET) was negative (-) then it was reduced to an absolute price so that it was positive. The third step was to calculate STOR (moisture storage capacity) which is a function of land use, soil texture, and root zone depth. After that, the fourth step was to calculate the
SM formula (the actual storage of soil moisture) which was then divided into two scenarios, Equation 4 and Equation 5.

\[
\text{SM} = \text{STOR} \times e^{-\left(\frac{\text{APWL}}{\text{STOR}}\right)} \text{, if } \text{APWL} \neq 0
\]

\[
\text{SM} = \text{STOR}, \text{ if } \text{APWL} = 0
\] (5)

The fifth step was to calculate ∆SM to find out the STOR value, whether negative or positive. If ∆SM was positive (+), then soil moisture storage was supplied from infiltration; if ∆SM was negative (-), then soil moisture storage was reduced due to evapotranspiration. ∆SM was calculated based on Equation 6. The current month's STOR minus the previous month's STOR.

\[
\Delta \text{SM} = \text{SM}_{\text{month}} - \text{SM}_{\text{previous month}}
\] (6)

The sixth step was to calculate the AET (actual evapotranspiration) value. The AET value was calculated based on the two scenarios described in Equations 7 and 8.

\[
\Delta \text{SM} > \text{PET}, \text{ then } \text{AET} = \text{PET}
\]

\[
\Delta \text{SM} < \text{PET}, \text{ then } \text{AET} = \text{P} + \Delta \text{SM}
\] (8)

The seventh step was to calculate the value of DEF (the water deficit) in Equation 9 and SUR (moisture surplus) in Equation 10. The results of DEF and SUR calculations are more clearly displayed in the graph of the relationship between monthly AET, PET, and P.

\[
\text{DEF} = \text{PET} - \text{AET}
\]

\[
\text{SUR} = \text{P} - (\text{AET} + \Delta \text{SM})
\] (10)

Step eight was to perform the R (Runoff) calculation. The assumption used for the calculation of R was that half of the rain falls into the surface, in a form of surface runoff; and half of it enters groundwater (Equation 11). When entering dry seasons, R is still there, R during the dry season is obtained from the groundwater reserve (baseflow). The details of the calculation for equation 11 are described in table 2. The first stage is by dividing ½ the surplus-value of December in the first row of the last column, followed by dividing ½ in the following month (first row of the first column and so on). The surplus in January is divided by ½ in the second row of the first column, then continued to be divided by ½ in the next column, and so on for the other months. The R modelled results are obtained from the total columns for each month (number with bold style). The result of R was then multiplied by the area of the study area.

\[
\text{R} = \frac{1}{2} (\text{SUR}_{\text{month}} + \text{SUR}_{\text{previous month}})
\] (11)
Table 2. Example calculation R modelled of Ayung Sub-Watershed

|       | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec   |
|-------|-----|-----|-----|-----|-----|------|------|-----|------|-----|-----|-------|
| Dec   | 30.10 | 15.05 | 7.53 | 3.76 | 1.88 | 0.94 | 0.47 | 0.24 | 0.12 | 0.06 | 0.03 | 60.21 |
| Jan   | 84.76 | 42.38 | 21.19 | 10.60 | 5.30 | 2.65 | 1.32 | 0.66 | 0.33 | 0.17 | 0.08 | 0.04 |
| Feb   | 114.86 | 84.90 | 42.45 | 21.23 | 10.61 | 5.31 | 2.65 | 1.33 | 0.66 | 0.33 | 0.17 | 0.08 |
| Mar   | 142.33 | 52.15 | 26.08 | 13.04 | 6.52 | 3.26 | 1.63 | 0.81 | 0.41 | 0.20 | 0.10 |
| Apr   | 123.32 | 17.74 | 8.87 | 4.44 | 2.22 | 1.11 | 0.55 | 0.28 | 0.14 | 0.07 |
| May   | 79.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| June  | 39.70 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| July  | 19.85 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Aug   | 9.93 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sept  | 4.96 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Oct   | 2.48 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Nov   | 1.24 | 11.08 | 5.54 | 11.70 | 66.04 |

2.3. Validation of the Water Balance

The Thornthwaite and Mather water balance method validation was carried out by comparing the R results (model) with primary and secondary discharge data (Equation 12). Comparisons were made in the form of calculating the accuracy in the form of the root mean square error (RMSE) percentage. RMSE can be accepted if the score is less than and close to 10% [22,29]. Other results can be found without using RMSE, namely by comparing the model discharge value with observed discharge multiplied by 100%; the closer to 100% the model is, the more accurate the result. The accuracy results can provide an idea of whether the Thornthwaite and Mather water balance methods can be applied somewhere. In addition, the analysis was also carried out by comparing the results of the Thornthwaite and Mather water balance methods in different climatic regions.

\[
\%RMSE = \frac{\sqrt{\frac{\sum(V_{\text{modelled}} - V_{\text{obs}})^2}{n}}}{\sum V_{\text{obs}}} \times 100 \times n
\]  

3. Results and Discussions

The analysis of the water balance in the Ayung Sub-watershed showed water surpluses in January-April and October-December (Figure 2), and water deficit in May-September. The highest surplus was in February with 169.80 mm or 46,790,587 m³/month, while the highest deficit was in August with 131.38 mm or 36,203,668 m³/month (Table 2). The runoff model for the Ayung sub-watershed showed that the highest discharge was in February with 142.33 mm or 15.13 m³/s and the lowest was in October with 1.24 mm or 0.13 m³/s. The score of calculating RMSE (%) of modeled R and observed R in the Ayung sub-watershed was 41.42%. This result indicates a weak correlation between modeled R and observed R. The modeled R values that underestimated R observed were found in June, July, October, November, and December; the modeled R values that were close to the observed R values were observed in January, February, March, August, and September; and the modeled R values that overestimated the observed R were found in April and May (Table 3).
Figure 2. Water Balance Graph of Ayung Sub-Watershed.

The analysis of the water balance in the Wampu Sub-watershed showed water surpluses in April-May and August-December (Figure 3), and water deficit in January-March and June-July. The highest water surplus was in October with 162.50 mm or 70,758,417 m³ / month, while the highest water deficit was in March with 50.65 mm or 22,055,342 m³ / month (Table 4). The results of the modeled runoff in Wampu Sub-watershed showed that the highest discharge was in November with 110 mm or 18.84 m³ / s and the lowest was in April with 2.64 mm or 0.44 m³ / s. The score of RMSE (%) calculation between modeled R and observed R in the Wampu sub-watershed was 65.58%. This result indicated a weak correlation and low accuracy of the two results. The modeled R values that underestimated observed R was found in January, February, March, April, June, July, and December; the modeled R values that were close to the observed R values were in May, August, September, and November (Table 3); and the overestimated modeled R-value of observed R-value occurred in October.
The analysis of the water balance in the Tondano Sub-watershed showed water surpluses in January-May and October-December (Figure 4), and water deficits in June-September. The highest surplus was in December with 107.85 mm or 15,143,064 m³ / month and the highest deficit was in September with 45.29 mm or 6,359,560 m³ / month (Table 5). The modeled runoff for the Tondano sub-watershed indicated that the highest discharge was in April with 124.73 mm or 6.76 m³ / s and the lowest was in October with 2.30 mm or 0.12 m³ / s. The score of RMSE (%) calculation between modeled R and observed R in the Tondano sub-watershed was 83.68%. This result indicated a weak and low correlation between the two results. The modeled R values which underestimated observed R were found in May-November and the modeled R that were close to the observed R were in January-April and December (Table 4). There was no overestimated modeled R-value from the observed R.

The analysis of the water balance in the Serayu Sub-watershed showed water surpluses in January-May and October-December (Figure 5), and water deficit in June-September. The highest water surplus was in December with 399.40 mm or 54,646,666 m³ / month, and the highest water deficit was in October with 75.30 mm or 10,302,689 m³ / month (Table 5). The analysis of the modeled runoff in the Serayu Sub-watershed revealed that the highest discharge was in March with 324.48 mm or 17.13 m³ / s, and the lowest was in October with 12.83 mm or 0.677 m³ / s. The score of RMSE (%) calculation between modeled R and observed R in Serayu sub-watershed was 53.77%. This result indicated a weak correlation. The modeled R values which underestimated observed R were found in June, May-November, while the modeled R values that were close to the observed score were found in January-April and December (Table 6). No modeled R-value was overestimated from the observed R.
### Table 3. Water Balance of Ayung Sub-Watershed.

|            | January | February | March | April | May | June | July | August | September | October | November | December |
|------------|---------|----------|-------|-------|-----|------|------|--------|-----------|---------|----------|----------|
| T (°C)     | 28.20   | 28.10    | 28.30 | 28.00 | 26.10 | 25.80 | 25.70 | 26.00 | 27.10     | 28.50   | 27.90    | 28.00    |
| P (mm)     | 350.00  | 330.00   | 280.00| 200.00| 100.00| 60.00 | 40.00 | 25.00 | 40.00     | 120.00  | 230.00   | 300.00   |
| PET (mm)   | 180.48  | 160.20   | 175.69| 164.51| 153.35| 148.04| 149.68| 159.04| 159.85    | 179.17  | 171.68   | 179.59   |
| P-PET (mm) | 169.52  | 169.80   | 104.31| 35.49 | -53.35| -85.04| -109.68| -134.04| -119.85   | -59.17  | 58.32    | 120.41   |
| A-PWL (mm) | 0.00    | 0.00     | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00      | 0.00    | 0.00     | 0.00     |
| SM (mm)    | 54.75   | 54.75    | 54.75 | 54.75 | 54.75 | 54.75 | 54.75 | 54.75 | 54.75     | 54.75   | 54.75    | 54.75    |
| ΔSM (mm)   | 0.00    | 0.00     | 0.00  | 0.00  | -34.08| -9.08 | -4.20 | -2.65 | 1.40      | 36.17   | 0.00     | 0.00     |
| AET (mm)   | 180.48  | 160.20   | 175.69| 164.51| 134.08| 69.08 | 44.20 | 27.65 | 38.60     | 107.55  | 171.68   | 179.59   |
| SUR (mm)   | 169.52  | 169.80   | 104.31| 35.49 | 0.00  | 0.00  | 0.00  | 0.00  | 0.00      | 0.00    | 2.15     | 12.41    |
| DEF (mm)   | 0.00    | 0.00     | 0.00  | 0.00  | 0.00  | 19.27 | 75.96 | 105.48| 121.25    | 71.62   | 0.00     | 0.00     |
| R modelled (mm) | 114.86 | 142.33   | 123.32| 79.40 | 39.70 | 19.85 | 9.93  | 4.96  | 2.48      | 1.24    | 11.70    | 66.04    |
| R modelled (m³/s) | 12.21 | 15.13    | 13.11 | 8.44  | 4.22  | 2.11  | 1.06  | 0.53  | 0.26      | 0.13    | 1.24     | 7.02     |
| R observed (m³/s) | 12.87 | 20.42    | 10.01 | 2.14  | 0.83  | 11.37 | 8.62  | 1.50  | 0.62      | 12.72   | 7.74     | 19.80    |

### Table 4. Water Balance of Wampa Sub-Watershed.

|            | January | February | March | April | May | June | July | August | September | October | November | December |
|------------|---------|----------|-------|-------|-----|------|------|--------|-----------|---------|----------|----------|
| T (°C)     | 25.65   | 25.17    | 26.46 | 26.34 | 26.97 | 26.96 | 26.49 | 26.10  | 25.83     | 25.93   | 25.53    | 25.59    |
| P (mm)     | 153.00  | 79.00    | 130.50| 155.50| 248.50| 153.00| 169.50| 207.00| 269.00    | 317.50  | 268.00   | 233.50   |
| PET (mm)   | 152.00  | 135.00   | 160.00| 155.00| 166.00| 161.00| 163.00| 157.00| 151.00    | 155.00  | 146.00   | 151.00   |
| P-PET (mm) | 1.00    | -56.00   | -29.50| 0.50  | 82.50 | -8.00 | 6.50  | 50.00 | 118.00    | 162.50  | 122.00   | 82.50    |
| A-PWL (mm) | 0.00    | 56.00    | 29.50 | 0.00  | 0.00  | 8.00  | 0.00  | 0.00  | 0.00      | 0.00    | 0.00     | 0.00     |
| SM (mm)    | 189.00  | 189.00   | 189.00| 189.00| 189.00| 189.00| 189.00| 189.00| 189.00    | 189.00  | 189.00   | 189.00   |
| ΔSM (mm)   | 0.00    | -48.46   | 21.15 | 27.31 | 0.00  | -7.83 | 7.83  | 0.00  | 0.00      | 0.00    | 0.00     | 0.00     |
| AET (mm)   | 152.00  | 127.46   | 109.35| 155.50| 166.00| 160.83| 163.00| 157.00| 151.00    | 155.00  | 146.00   | 151.00   |
| SUR (mm)   | 1.00    | 0.00     | 0.00  | 0.00  | 82.50 | 0.00  | 0.00  | 50.00 | 118.00    | 162.50  | 122.00   | 82.50    |
| DEF (mm)   | 0.00    | 7.54     | 50.65 | 0.00  | 0.00  | 0.17  | 0.00  | 0.00  | 0.00      | 0.00    | 0.00     | 0.00     |
| R modelled (mm) | 21.10 | 10.56    | 5.28  | 2.64  | 42.57 | 21.28 | 18.10 | 45.70 | 82.96     | 105.70  | 110.00   | 96.20    |
| R modelled (m³/s) | 3.54 | 1.77     | 0.89  | 0.44  | 7.15  | 3.57  | 3.04  | 7.68  | 13.94     | 17.76   | 18.48    | 16.16    |
| R observed (m³/s) | 24.55 | 13.72    | 11.24 | 12.77 | 13.01 | 10.83 | 12.74 | 12.27 | 14.47     | 15.14   | 18.28    | 24.17    |

RMSE 41.42

RMSE 65.58
The water balance graphs, especially the rainfall character, of the Wampu (Sumatra) and Tondano (Sulawesi) sub-watersheds are quite different from the graphs of the Serayu and Ayung sub-watersheds (Java and Bali). This result is also reinforced by research [23] finding that there are differences in rain zoning from 1985-2010 in several regions, including Sumatra (B), Sulawesi (C), and Java and Bali (A). The rain pattern of the water balance of the Wampu Sub-watershed has two peaks in April-May and August-December because the pattern in region B is influenced by movements of the southward and northward inter-tropical convergence zone (ITCZ) [24]. Rainfall graphs for Serayu and Ayung sub-watersheds are in accordance with the pattern of region A with lows in the months of May-September and highs in October-April. Meanwhile, the rain pattern in the Tondano sub-watershed is the same as type C, with 1 rainfall peak in June-July, and other highs in January-April and November-December.

Rain in the tropical area showed a higher value compared to other regions. This implicates the runoff value in the four study locations have greater than in other climatic areas. Rainfall in Iran with four monsoons is 296 mm/year and the runoff is 30 mm/year [9] smaller than the study location. Rainfall in the arid US region is 98 mm/year and the mean runoff is 35 mm [10] smaller than the study location. Rainfall in the sub-tropical region of Georgia US is 1,200 mm/year with runoff is 300 mm/years [27], which is still smaller than the study area. Rainfall in the tropical region of Costa Rica is 2697 mm/year and runoff 169 mm/year [26]. These results have a value close to the study location for the rain value, but the runoff is relatively small because the forest becomes the dominant of land use (SM 200). Rainfall in tropical India obtained 1,175 mm/year rain and 255 for the runoff [27]. Rainfall in other parts of India is 1,393 mm / year and Runoff 88 [6] both values are still smaller than the four study locations. These results are still far from the study location for the value of rain and runoff (forest dominance of SM 49). Rainfall in tropical Equador is 843 mm/year and runoff 202.2 mm/years [2] these results are still below the value of the four study locations. Another tropical area is in Kulon Progo Regency that has similarities with the four study locations with 2,600 mm/year of rain and runoff 633 [7].

Other factors causing the different of Water Balance is in the PET, especially in arid and semi-arid areas. The results of Thornthwaite and Mather method were quite inaccurate in Aswan Dam Egypt because the PET value was underestimated, with RMSE of 80 and 110% [22]. The same method was applied in Portugal and indicated that the results of the water balance method showed underestimated PET and high runoff values [25]. The application of the Thornthwaite and Mather method in the semi-
arid region shows that the PET accuracy is by 69% and its modification by adding the Willmot equation resulted in better accuracy, by 77% [12]. PET values in Southwest Asia range from 300-600 mm [13] which are quite larger compared to the tropical regions of this study sites.

![Figure 5. Water Balance Graph of Serayu Sub-Watershed.](image)

However, after being compared with the results of the Thornthwaite and Mather method in other tropical areas, the PET value of this study location is not much different from the values of other areas. With this consideration, the PET value of this study does not need to be corrected. The global yield of the Thornthwaite and Mather method PET in the tropics ranges from 1000-1100 mm / year [1]. In addition, the Thornthwaite and Mather method is also applied in Costa Rica with an accuracy of 40-76% between modeled R and observed R [26]. Other tropical applications are applied in India with underestimated modeled R values compared to the observed R values [27], however, the PET, AET, and Precipitation values are almost close to the values of the study location. The applications of the Thornthwaite and Mather method in subtropical India have an average accuracy of 88.33% [6]. In addition, in Indonesia, its application in Kulon Progo, DIY is characterized by almost the same results in the values of PET, AET, P and R as the 4 sub-watersheds in the study locations [7].

Comparison of the results of other Thornthwaite and Mather method applications shows many variations. The results of Thornthwaite and Mather water balance in the tropical watershed region of Ecuador show PET values ranging from 55-70 mm / month, AET of 24-70 mm / month, and SUR of 7-41 mm / month [2]. These results are close to their values in the tropical region near the ITCZ. Another Thornthwaite and Mather method applied in the arid region of Migan Watershed area (Iran) showed a very small precipitation value compared to our study locations, around 30-50 mm / month; higher AET values than the values our study locations, with values of around 50-400 mm / month; and PET ranged from 30 to 120 mm / month [9]. Other results in the semi-arid area of California, the US showed that PET values range from 30 to 197 mm/month, the surplus is only occurred in January with 291 mm/month, with runoffs occurring for 6 months averagely ranging from 53 to 212 mm / month [10]. These results are also smaller compared to the results in our study locations.
Table 5. Water Balance of Tondano Sub-Watershed.

|       | January  | February | March  | April  | May   | June  | July  | August | September | October | November | December |
|-------|----------|----------|--------|--------|-------|-------|-------|--------|-----------|---------|----------|----------|
| T (°C) | 26.28    | 26.24    | 26.26  | 26.67  | 27.14 | 27.27 | 27.03 | 27.13  | 27.21     | 27.00   | 26.55    | 25.23    |
| P (mm) | 184.02   | 225.91   | 216.47 | 253.71 | 200.23 | 125.17| 148.53| 120.74 | 113.44    | 156.04  | 196.13   | 258.44   |
| PET (mm) | 158.22  | 142.91   | 158.88 | 157.12 | 166.24 | 162.00| 165.77| 165.07 | 160.64    | 163.91  | 155.11   | 150.59   |
| P-PET (mm) | 25.80   | 83.00    | 57.59  | 96.99  | 33.99  | -36.83| -17.04| -44.33 | -47.20    | -7.87   | 41.10    | 107.85   |
| APWL (mm) | 0.00     | 0.00     | 0.00   | 0.00   | 0.00   | 36.83 | 17.04 | 44.33  | 47.20     | 7.87    | 0.00     | 0.00     |
| STOR (mm) | 112.26  | 112.26   | 112.26 | 112.26 | 112.26 | 112.26| 112.26| 112.26 | 112.26    | 112.26  | 112.26   | 112.26   |
| SM (mm) | 112.26   | 112.26   | 112.26 | 112.26 | 112.26 | 80.86 | 96.45 | 75.64  | 73.73     | 104.66  | 112.26   | 112.26   |
| ΔSM (mm) | 0.00     | 0.00     | 0.00   | 0.00   | 0.00   | -31.40| 15.59 | -20.81| -1.91     | 30.93   | 7.60     | 0.00     |
| AET (mm) | 158.22   | 142.91   | 158.88 | 157.12 | 166.24 | 156.57| 132.94| 141.55 | 115.35    | 125.11  | 155.11   | 150.59   |
| SUR (mm) | 25.80    | 83.00    | 57.59  | 96.99  | 33.99  | 0.00  | 0.00  | 0.00   | 0.00      | 33.42   | 107.85   | 107.85   |
| DEF (mm) | 0.00     | 0.00     | 0.00   | 0.00   | 0.00   | 5.43  | 32.63 | 23.52  | 45.29     | 38.80   | 0.00     | 0.00     |
| R modelled (mm) | 39.80 | 96.47    | 85.07  | 124.73 | 72.21  | 36.10 | 18.10 | 9.00   | 4.51      | 2.30    | 17.80    | 62.80    |
| R observed (m³/s) | 2.16     | 5.23     | 4.61   | 6.76   | 3.91   | 1.96  | 0.98  | 0.49   | 0.24      | 0.12    | 0.96     | 3.40     |
| RMSE   | 4.00     | 10.00    | 10.00  | 13.00  | 12.00  | 13.00 | 13.00 | 13.00  | 10.00     | 10.00   | 8.00     | 7.00     |

Table 6. Water Balance of Serayu Sub-Watershed.

|       | January  | February | March  | April  | May   | June  | July  | August | September | October | November | December |
|-------|----------|----------|--------|--------|-------|-------|-------|--------|-----------|---------|----------|----------|
| T (°C) | 17.83    | 17.67    | 17.85  | 17.80  | 18.00 | 17.66 | 17.22 | 16.98  | 16.80     | 17.27   | 17.54    | 17.38    |
| P (mm) | 465.00   | 404.00   | 457.00 | 379.00 | 189.00 | 94.00 | 30.00 | 4.00   | 14.00     | 134.00  | 389.00   | 496.00   |
| PET (mm) | 105.30  | 92.60    | 103.60 | 98.00  | 102.60 | 93.40 | 91.90 | 89.90  | 86.00     | 96.10   | 99.60    | 96.60    |
| P-PET (mm) | 359.70  | 311.40   | 353.40 | 281.00 | 86.40  | 0.60  | -61.90| -85.90 | -72.00    | 37.90   | 289.40   | 399.40   |
| APWL (mm) | 0.00     | 0.00     | 0.00   | 0.00   | 0.00   | 61.90 | 85.90 | 72.00  | 0.00      | 0.00    | 0.00     | 0.00     |
| STOR (mm) | 145.00  | 145.00   | 145.00 | 145.00 | 145.00 | 145.00| 145.00| 145.00 | 145.00    | 145.00  | 145.00   | 145.00   |
| SM (mm) | 145.00   | 145.00   | 145.00 | 145.00 | 145.00 | 145.00 | 95.00 | 52.00  | 145.00    | 145.00  | 145.00   | 145.00   |
| ΔSM (mm) | 0.00     | 0.00     | 0.00   | 0.00   | 0.00   | 0.00  | -50.00| -43.00 | -20.15    | 113.15  | 0.00     | 0.00     |
| AET (mm) | 150.59   | 148.53   | 120.74 | 113.44 | 156.04 | 196.13| 258.44| 150.59 | 155.11    | 112.26  | 112.26   | 112.26   |
| SUR (mm) | 279.70   | 295.55   | 324.48 | 302.74 | 194.57 | 118.88| 70.24 | 40.52  | 12.83     | 151.12  | 275.21   | 275.21   |
| DEF (mm) | 279.70   | 295.55   | 324.48 | 302.74 | 194.57 | 118.88| 70.24 | 40.52  | 12.83     | 151.12  | 275.21   | 275.21   |
| R modelled (m³/s) | 14.76   | 15.60    | 17.13  | 15.98  | 10.27  | 6.28  | 3.71  | 2.139  | 1.212     | 0.677   | 7.98     | 14.53    |
| R observed (m³/s) | 19.00   | 21.00    | 19.00  | 21.00  | 16.00  | 12.00 | 10.00 | 8.00   | 12.00     | 18.00   | 18.00    | 18.00    |

RMSE 83.68

RMSE 53.77
Another factor that distinguishes the water balance in different climates is the SM value. SM gives different effects on evapotranspiration and annual deficits [30]. Besides that, SM has some impact on the Runoff. The results of the four study areas have an average SM value, around 120-190 mm which is classified as high with the dominance of land use as forests and agriculture. The SM value in the Arid Iran region is 44 mm with the dominant empty land [9] the SM value is still below the study location. In the US semi-arid area, the SM value is 35 mm with the dominant agricultural land use [10] that value is still lower than study location. In the tropics of Ecuador, the value of SM is 30 with the dominant forest land use [2]. The tropical region of Costa Rica has an SM value; 200 [26] which has the same value as the study location.

The topographic factor is not included in calculating the water balance because already in temperature and rain data. The differences in elevation certainly have an impact on variances in temperature and rainfall. River morphometry is not included in the Thornthwaite and Mather water balance calculations because the basic model uses climatic and physical parameters (vegetation and soil texture). Morphometric factors are used to determine the amount of runoff in a watershed, namely the runoff multiplied by the watershed area. The results water balance of this study showing that four watersheds have weak RMSE. The Thornthwaite and Mather method needs to be modified in the tropics so that it is applicable and has an acceptable RMSE. To improve the RMSE scores to go below 50%, it is necessary to add rain and temperature data with a period of 20-30 years [26,6].

4. Conclusions
The RMSE results of the Thornthwaite and Mather method in Indonesian tropical areas showed weak correlation values in the Ayung, Serayu, Bingei and Tondano sub-watersheds. The results of the Thornthwaite and Mather method validation in other tropical areas show that the validation values are inaccurate, and their characteristics are almost the same as the values of our study locations. Based on the result we need to modify the Thornthwaite and Mather method in the tropics.

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