Thornthwaite Models for Estimating Potential evapotranspiration in Medan City

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Abstract. Evapotranspiration plays a big role in the hydrology process. Potential Evapotranspiration (PET) always keeps soil moisture available, although an amount of water evaporates through evaporation and transpiration. The Thornthwaite equation uses air temperature and latitude from meteorological observations for estimating PET. Medan City is one of the biggest cities in Indonesia that have a problem with land-use change that affected water balance. This study is to estimate the PET and to learn the water balance in Medan City. The monthly temperature data for the period 2011-2020 is collected from three meteorological stations for estimating PET using the Thornthwaite equation. The highest monthly temperature is in Belawan Maritime Meteorological Station yet the lowest rainfall. The trends of PET depend on the month. The highest PET in Jan.-Apr. and Sep.-Dec. are in Belawan Maritime Meteorological Station, while the highest PET in May-Aug. is in Indonesia Agency for Meteorology Climatology and Geophysics Region I Medan. The P-PET has shown negative and positive values. The lowest P-PET is found in Belawan Maritime Meteorological Station in March and the highest P-PET is found in Indonesia Agency for Meteorology Climatology and Geophysics Region I Medan in October.

1. Introduction
Evapotranspiration has an important role in the hydrology process, especially related to water balance that exhibits the values of inflow, outflow and alteration in water storage in the area or water body [1]. Evapotranspiration combines two important processes, evaporation and transpiration. Water evaporates from soil and water body through evaporation and it also evaporates from plant tissue through transpiration [2,3]. Evapotranspiration is also used to detect water needs in dry areas [4,5], to manage water resources and land resources [6], as well as to provide plant water needs in common [3].

Potential Evapotranspiration (PET) is a condition when soil moisture availability is unlimited, although an amount of water has been lost through evaporation and transpiration [3,7,8]. PET is used to estimate the evapotranspiration value of an area through the weather approach [3]. In the humid area, PET tends to have a similar value to actual evapotranspiration [8]. There are many methods for estimating the PET rate based on hydrological models and also meteorological observations [9,10]. A simple method for estimating PET is the Thornthwaite equation. The Thornthwaite equation developed by Thornthwaite (1948) uses air temperature and latitude from meteorological observations [2,10]. The Thornthwaite equation inclines to overvalue PET in humid regions, while it inclines to undervalue PET in the arid and semiarid areas [5].

The climate change phenomenon as well as population growth, which implicates land-use change, have affected the PET rate and disrupted the hydrological process [10]. These conditions often occur...
in big cities including Medan City. Medan City is the capital of North Sumatra Province that has the humidity of around 78-82 % and an average temperature around 26-28°C [11]. Population and economy grow rapidly in this city, while ecology does not go hand in hand. This study aims to estimate the PET rate in Medan City using the Thornthwaite equation and also to learn water balance through relations between precipitation and PET rate.

2. Methods
Medan City (latitude 3°34’58.80” and longitude 98°40’1.20”) is the capital of North Sumatra Province was chosen as the study area. The materials used in this research were daily and monthly climate data for the period 2011-2020 from three meteorological stations around Medan City (Table 1). There are Indonesia Agency for Meteorology Climatology and Geophysics Region I Medan, Sampali Climatology Station, and Belawan Maritime Meteorological Station.

| No. | Station Name                                      | Location                     |
|-----|--------------------------------------------------|------------------------------|
| 1   | Meteorology Climatology and Geophysics Region I Medan | 3°32’23”N98°38’13”E          |
| 2   | Sampali Climatology Station                      | 3°37’14”N98°42’59”E          |
| 3   | Belawan Maritime Meteorological Station           | 3°47’07”N98°42’53”E          |

Every meteorological data must be examined for quality and completeness. The threshold of data quality control was 10% [6]. For filling the missing temperature data, make sure to check the percentage of missing data. If no more than 10%, fill in the missing temperature data using the average data in the station [12]. For filling the missing precipitation data used normal ratio method [13]. The Thornthwaite equation was mostly used to estimate the PET based on the monthly averaged temperatures. The link between the monthly averaged temperatures \((T)\) and potential evapotranspiration \((PET)\) is provided by Thornthwaite [14].

\[
PET^* = 16 \left[ \frac{10I^o}{I} \right]^a \tag{1}
\]

\[
I = \sum_{j=1}^{12} i_j \tag{2}
\]

\[
i = \left[ \frac{T}{5} \right]^{1.514} \tag{3}
\]

\[
a = 675 \times 10^{-9} I^3 - 771 \times 10^{-7} I^2 + 1792 \times 10^{-5} I + 0.49239 \tag{4}
\]

\[
PET = PET^* \times f \tag{5}
\]

\(PET^*\): normative potential evapotranspiration values (mm month\(^{-1}\)), \(PET\): corrected potential evapotranspiration values (mm month\(^{-1}\)), \(T\): the monthly averaged temperatures \({}^\circ C\), \(I\): annual heat index, \(i\): monthly heat index, \(a\): constant, \(f\): correction factor.
3. Result and Discussion
The location of the meteorological stations around Medan City shows in Figure 1 and every station has different latitude (Table 2). According to the Thornthwite equation (1,2,3,4,5) previously, latitude has affected the monthly corrected potential evaporation (PET) using the correction factor of sunlight duration and amount of daily light for each month [1,14].

![Location of the study area in Medan City](image)

**Table S2. The correction factor of latitude and month [14]**

| No. Station | Latitude | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. |
|-------------|----------|------|------|------|------|-----|------|------|------|------|------|------|------|
| 1           | 39°N     | 0.85 | 0.84 | 1.03 | 1.11 | 1.23 | 1.24 | 1.26 | 1.18 | 1.04 | 0.96 | 0.84 | 0.82 |
| 2           | 18°N     | 0.96 | 0.905| 1.03 | 1.055| 1.095| 1.13 | 1.155| 1.095| 1.02 | 1    | 0.94 | 0.955|
| 3           | 3°N      | 1.03 | 0.935| 1.035| 1.015| 1.05 | 1.02 | 1.05 | 1.045| 1.01 | 1.035| 1    | 1.05 |

Figure 2a shows that the highest monthly temperature is in Belawan Maritime Meteorological Station, it caused the station is nearby the sea and also has the lowest latitude. The lower the height of the measurement station, the higher the air temperature [15]. For the PET (Figure 2b), the trends depend on the month. The highest PET in Jan.-Apr. and Sep.-Dec are in Belawan Maritime Meteorological Station, while the highest PET in May-Aug. is in Indonesia Agency for Meteorology Climatology and Geophysics Region I Medan. Land use has affected the PET value, land degradation that is the change in land cover from vegetated land to open or built areas causes heating of air temperature and is a significant factor in increasing evapotranspiration [15]. The difference of PET is influenced by the size or the small value of temperature, soil conditions, climate, evaporation, and local vegetation [10].
Figure 2. The average monthly temperature (a) and the PET (b) in Indonesia Agency for Meteorology Climatology and Geophysics Region I Medan (1); Sampali Climatology Station (2); and Belawan Maritime Meteorological Station (3).

Figure 3. Precipitation value (P) in Indonesia Agency for Meteorology Climatology and Geophysics Region I Medan (1); Sampali Climatology Station (2); and Belawan Maritime Meteorological Station (3).

The highest rainfall detects in Indonesia Agency for Meteorology Climatology and Geophysics Region I Medan and the lowest is in Belawan Maritime Meteorological Station, although the average monthly temperature is the highest. It is because the air temperature has a negative effect on rainfall [16]. One of the factors that affected water balance (P-PET) is evapotranspiration. Water evaporates from the plant through transpiration, surface evaporation, and groundwater funds are consumed by evapotranspiration. The P-PET shows negative and positive values (Table 4). The lowest P-PET is found in Belawan Maritime Meteorological Station in March. The negative values indicate the amount of rainfall cannot escalate the potential of water needs from areas covered by vegetation. Otherwise,
the highest P-PET is found in Indonesia Agency for Meteorology Climatology and Geophysics Region I Medan in October. The positive values of P-PET show that there is an excess amount of water for a specified period of a year to bring back soil moisture [15].

Table 3. Precipitation (P) and water balance (P-PET) in Indonesia Agency for Meteorology Climatology and Geophysics Region I Medan (1), Sampali Climatology Station (2); and Belawan Maritime Meteorological Station (3)

| Month      | 1  | 2  | 3  |
|------------|----|----|----|
| P          |    |    |    |
| P-PET      |    |    |    |
| P          |    |    |    |
| P-PET      |    |    |    |
| P          |    |    |    |
| P-PET      |    |    |    |

4. Conclusions
The highest monthly temperature is in Belawan Maritime Meteorological Station yet the lowest rainfall. It is because the air temperature has a negative effect on rainfall. The trends of PET depend on the month. The highest PET in Jan.-Apr. and Sep.-Dec are in Belawan Maritime Meteorological Station, while the highest PET in May-Aug. is in Indonesia Agency for Meteorology Climatology and Geophysics Region I Medan. The P-PET has shown negative and positive values. The lowest P-PET is found in Belawan Maritime Meteorological Station in March and the highest P-PET is found in Indonesia Agency for Meteorology Climatology and Geophysics Region I Medan in October.

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