Sensitivity of methods for estimating potential evapotranspiration to climate change

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Abstract. Global climate change occurs because of the addition of absorbing gases into the atmosphere, which can be interpreted as the greenhouse effect. Changes that occur in temperature will be followed by changes in other climatic elements, including rainfall, solar radiation, air humidity, and wind speed. The purpose of this study is to determine the sensitivity of potential evapotranspiration calculation methods to climate change and to determine the diversity of results based on differences in the calculation structure and the needed data. The utilized methods to estimate the sensitivity of potential evapotranspiration (ETp) to climate change were the Thornthwaite, Blaney-Criddle, FAO without correction, Makkink, Ivanov, Hargreaves-74, Modified Penman, and Penman-Monteith methods. The analysis was carried out using climate data from three climatological station locations in Central Sulawesi, which are the Singkoyo, Kulawi, and Bora Stations. The calculation results showed that the Thornthwaite and Blaney-Criddle methods were relatively the most sensitive to temperature changes, followed by the Penman-Monteith, Ivanov, Hargreaves 74, and Modified Penman methods. The FAO and Makkink methods showed relatively little sensitivity.

Keywords: climate, potential evapotranspiration, sensitivity

1. Introduction
Global climate change occurs because of the addition of absorbing gases into the atmosphere, which can be interpreted as the greenhouse effect. Changes that occur in temperature will be followed by changes in other climate elements such as rainfall, solar radiation, air humidity, and wind speed [1].

An area with high evaporation where rainfall is inadequate and uneven will be severely disrupted by the condition of the water balance, and this will cause problems, especially for activities that require water and including agricultural activities.

To estimate evapotranspiration, there are many methods available, in which their calculation processes utilize climate data, including temperature, solar radiation, air humidity, and wind speed. The data is expected to experience changes in response to climate change, especially changes in temperature caused by increased concentrations of carbon dioxide gas and other gases in the earth’s atmosphere.

To obtain information about the effect of climate change on evapotranspiration, it is necessary to analyse the sensitivity of evapotranspiration to climate change for several methods. Climate data were collected from three climatology stations in Central Sulawesi.
The aim of this study is to determine the sensitivity of potential evapotranspiration estimation methods to climate change and to determine the diversity of the results by differences in evapotranspiration estimates, the calculation structure, and the needed data.

2. Materials and Methods

2.1. Description of the Study

The data used in this study were obtained from 3 climatology stations in Central Sulawesi (Table 1).

The materials used in this analysis are secondary data in the form of daily average air temperature, solar radiation, solar irradiation time, air humidity, and wind speed (Table 2). The utilized equipment included calculators, stationery, and personal computers.

### Table 1. Climatology station names and positions

| No. | Station                                      | Location                      | Period (years) | Position                  | Sea Water Level |
|-----|----------------------------------------------|-------------------------------|----------------|---------------------------|-----------------|
| 1   | Singkoyo Watershed                           | Singkoyo                     | 1986 - 2017    | 01° 26' 51" South Latitude | +11.00 m       |
|     | Boladangko/Kulawi Watershed                 |                               | (32 years)     | 122° 20’ 09” East Longitude |                |
| 2   | Miu                                          |                               | 2002 - 2018    | 01° 26' 55.4” South Latitude | +600.00 m      |
|     | Palu                                         |                               | (17 years)     | 119° 59’ 7.6” East Longitude |                |
| 3   | Bora Palu Watershed                          |                               | 1993 - 2017    | 01° 11’ 39” South Latitude | +75.00 m       |
|     |                                              |                               | (25 years)     | 119° 55’ 53” East Longitude |                |

### Table 2. Average climatology data

| No. | Station                                      | Climate | Symbol | Unit          | Jan   | Feb   | Mar   | Apr   | May   | Jun   | Jul   | Aug   | Sep   | Oct   | Nov   | Dec   |
|-----|----------------------------------------------|---------|--------|---------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 1   | Singkoyo                                    |         |        |               | 28.62 | 28.02 | 28.29 | 27.98 | 27.70 | 26.79 | 26.39 | 26.11 | 27.01 | 27.88 | 28.20 | 28.30 |
|     |                                              | Temperature Relative | T (°C)     | 87.22 | 87.83 | 87.52 | 87.52 | 88.64 | 90.51 | 90.46 | 89.46 | 85.64 | 85.09 | 84.92 | 85.74 |
|     |                                              | Humidity | RH (%)   | 36.91 | 35.69 | 38.12 | 37.82 | 36.87 | 32.76 | 33.74 | 38.34 | 45.54 | 45.57 | 41.71 | 36.66 |
|     |                                              | Wind Speed | V (km/d) | 42.46 | 44.57 | 45.62 | 47.49 | 43.97 | 32.17 | 29.19 | 31.40 | 49.22 | 52.81 | 55.12 | 44.63 |
|     |                                              | Sunshine | S (%)    | 424.50 | 395.20 | 348.10 | 309.00 | 257.70 | 220.30 | 265.30 | 283.50 | 365.10 | 483.20 | 483.80 | 373.30 |
| 2   | Boladangko/Kulawi                           |         |        |               | 25.16 | 24.92 | 25.91 | 25.82 | 25.69 | 25.21 | 25.91 | 25.71 | 26.05 | 25.78 | 25.58 | 25.44 |
|     |                                              | Temperature Relative | T (°C)     | 96.86 | 94.81 | 96.92 | 97.22 | 96.43 | 96.89 | 95.47 | 96.28 | 96.66 | 96.87 | 97.19 | 96.96 |
|     |                                              | Humidity | RH (%)   | 67.11 | 72.75 | 83.17 | 73.19 | 76.36 | 79.27 | 82.73 | 93.54 | 93.15 | 92.99 | 76.29 | 69.95 |
|     |                                              | Wind Speed | V (km/d) | 35.61 | 40.11 | 42.75 | 46.65 | 48.76 | 43.32 | 53.20 | 56.88 | 56.48 | 53.54 | 47.21 | 39.52 |
|     |                                              | Sunshine | S (%)    | 424.50 | 395.20 | 348.10 | 309.00 | 257.70 | 220.30 | 265.30 | 283.50 | 365.10 | 483.20 | 483.80 | 373.30 |
| 3   | Bora Palu Watershed                          |         |        |               | 27.85 | 27.95 | 28.05 | 28.25 | 28.24 | 28.24 | 27.90 | 27.97 | 28.22 | 28.60 | 28.50 | 28.29 | 28.7 |
|     |                                              | Temperature Relative | T (°C)     | 79.79 | 79.48 | 78.78 | 78.38 | 78.63 | 79.24 | 78.83 | 78.35 | 78.26 | 78.67 | 79.52 | 79.31 |
|     |                                              | Humidity | RH (%)   | 65.21 | 69.57 | 78.88 | 76.36 | 64.94 | 59.54 | 62.98 | 70.44 | 79.63 | 79.88 | 72.81 | 63.37 |
|     |                                              | Wind Speed | V (km/d) | 48.91 | 47.17 | 52.29 | 55.75 | 60.94 | 58.16 | 59.64 | 66.45 | 62.31 | 58.70 | 56.65 | 50.28 |
|     |                                              | Sunshine | S (%)    | 403.40 | 543.90 | 401.30 | 356.10 | 372.80 | 358.60 | 405.10 | 406.10 | 447.40 | 478.40 | 417.30 | 417.20 |
2.2. Literature Review

a) Thornthwaite Method
This method was developed in 1948 in the United States in a temperate area, with the following equation [1-5]:

\[ I = \sum_{M=1}^{12} \left[ \frac{T}{5} \right]^{1.51} \]  

(1)

b) Blaney-Criddle Method
The Blaney-Criddle method is widely used to estimate the water needs of plants using the following equation [1-3]:

\[ ET_0 = P \left( 0.46 T + 8.13 \right) \]  

(2)

c) FAO Method without correction
This method is based on the intensity of solar radiation, with the following equation [2]:

\[ ET_0 = \left[ \frac{\delta}{\delta + \tau} \cdot Es \right] - 0.30 \]  

(3)

d) Makkink Method
This method is based on the intensity of solar radiation, with the following equation [2, 4, 6]:

\[ ET_0 = 0.61 \left[ \frac{\delta}{\delta + \tau} \cdot Es \right] \]  

(4)

e) Ivanov Method
This method was developed in 1959 based on temperature data and humidity, with the following equation [2]:

\[ ET_0 = 0.0018 \left( 25 + T \right)^2 \left( 100 - RH \right) \]  

(5)

f) Hargreaves 74 Method
This method was developed in 1959 based on air temperature and humidity, with the following equation [1-4]:

\[ ET_0 = 3.96 + 0.966 Fb \left( 1.87 T + 32 \right)^{0.166} \left( 100 - RH \right)^{0.5} \]  

(6)

g) Modified Penman Method
The Modified Penman method was developed based on the Penman equation by Doorborens and Pruitts (1997), with the following equation [1-3, 5]:

\[ ET_0 = C \left( W \cdot Rn + (1 - W) \cdot f (u) \cdot (e_d - e_a) \right) \]  

(7)

h) Penman-Montith Method
The Penman-Montith method was developed by the Food Agriculture Organization (FAO) to renew and provide a standard method that can be used for all types of climates – both humid and dry – that affect an area, using the following equation [7-17]:

\[ ET_0 = \frac{0.408 \cdot \Delta \left( Rn - G \right) + \gamma \frac{900}{U_2 \cdot (e_d - e_a)}}{\Delta + \gamma \left( 1 + 0.34 \cdot U_2 \right)} \]  

(8)
2.3. Framework
These are the necessary steps to complete this research: 1) the basic value of potential evapotranspiration (ETp) without climate change was determined using several empirical methods, and 2) the sensitivity of each method to changes that occur in temperature was analysed, specifically by varying the temperature variables that are inputted into the calculation, while other variables remained fixed. The magnitude of the change in temperature used in the analysis is from 0 °C to 3 °C, with a change or increase interval of 0.5 °C [18].

3. Results and Discussion

3.1. Evapotranspiration Calculation Results

| No. | Method                                | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Average |
|-----|---------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| 1   | Thornthwaite (Thorn)                  | 5.82| 5.08| 4.84| 5.33| 5.14| 4.90| 4.76| 5.14| 5.61| 5.54| 5.39| 4.73| 5.19    |
| 2   | Blaney-Criddle (B-C)                  | 5.75| 5.67| 5.71| 5.67| 5.64| 5.52| 5.47| 5.44| 5.55| 5.66| 5.70| 5.71| 5.62    |
| 3   | FAO without correction (FAO)          | 6.66| 9.08| 6.62| 5.84| 6.13| 5.88| 6.67| 6.69| 7.41| 7.95| 6.90| 6.90| 6.89    |
| 4   | Makkink (Mak)                         | 6.93| 9.38| 6.89| 6.10| 6.39| 6.14| 6.94| 6.96| 7.69| 8.23| 7.17| 7.17| 7.17    |
| 5   | Ivanov (Iva)                          | 2.13| 2.12| 2.06| 2.10| 1.83| 1.53| 1.46| 1.60| 2.33| 2.42| 2.56| 2.35| 2.04    |
| 6   | Hargreaves-74 (Harg)                  | 3.95| 3.70| 3.79| 3.53| 3.08| 2.64| 2.69| 3.01| 3.87| 4.18| 4.27| 4.12| 3.57    |
| 7   | Penman (Pen)                          | 4.01| 4.16| 4.29| 4.19| 3.84| 3.23| 3.17| 3.37| 4.25| 4.70| 4.55| 4.08| 3.99    |
| 8   | Penman-Montieth (P-M)                 | 3.64| 3.88| 3.88| 3.75| 3.40| 2.84| 2.76| 2.95| 3.76| 4.19| 4.04| 3.64| 3.55    |

Figure 1. Comparison of evapotranspiration results for all methods (Singkoyo Station)
Table 4. Evapotranspiration calculation results for all methods (Kulawi Station), mm/day

| No. | Method                      | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Average |
|-----|-----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| 1   | Thornthwaite (Thorn)        | 3.69| 3.82| 4.07| 4.16| 3.96| 3.84| 4.07| 3.96| 4.29| 4.00| 4.03| 3.83| 3.98    |
| 2   | Blaney-Criddle (B-C)        | 5.32| 5.29| 5.41| 5.40| 5.39| 5.33| 5.41| 5.39| 5.43| 5.40| 5.37| 5.35| 5.37    |
| 3   | FAO without correction (FAO)| 6.64| 9.05| 6.61| 5.83| 6.11| 5.87| 6.67| 6.69| 7.40| 7.93| 6.88| 6.88| 6.88    |
| 4   | Makkink (Mak)               | 6.91| 9.35| 6.87| 6.09| 6.38| 6.13| 6.94| 6.96| 7.68| 8.22| 7.15| 7.15| 7.15    |
| 5   | Ivanov (Iva)                | 0.46| 0.80| 0.46| 0.43| 0.47| 0.47| 0.47| 0.46| 0.52| 0.47| 0.43| 0.45| 0.52    |
| 6   | Hargreaves-74 (Harg)        | 1.88| 2.30| 1.85| 1.66| 1.71| 1.51| 1.87| 1.83| 1.89| 1.90| 1.81| 1.85| 1.84    |
| 7   | Penman (Pen)                | 3.29| 3.63| 3.74| 3.72| 3.62| 3.32| 3.76| 4.02| 4.12| 4.03| 3.74| 3.40| 3.70    |
| 8   | Modified Penman-Montieth (P-M)| 3.12| 3.32| 3.47| 3.5  | 3.33| 2.95| 3.34| 3.63| 3.82| 3.78| 3.48| 3.21| 3.41    |

Figure 2. Comparison of evapotranspiration results for all methods (Kulawi Station)

Table 5. Evapotranspiration calculation results for all methods (Bora Station), mm/day

| No. | Method                      | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Average |
|-----|-----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| 1   | Thornthwaite (Thorn)        | 5.19| 5.63| 5.35| 5.70| 5.51| 5.40| 5.28| 5.48| 6.00| 5.72| 5.73| 5.20| 5.52    |
| 2   | Blaney-Criddle (B-C)        | 5.65| 5.67| 5.68| 5.70| 5.70| 5.66| 5.67| 5.70| 5.75| 5.73| 5.71| 5.66| 5.69    |
| 3   | FAO without correction (FAO)| 6.66| 9.09| 6.63| 5.85| 6.14| 5.89| 6.69| 6.71| 7.43| 7.96| 6.91| 6.90| 6.90    |
| 4   | Makkink (Mak)               | 6.93| 9.39| 6.90| 6.11| 6.40| 6.15| 6.96| 6.98| 7.71| 8.25| 7.18| 7.17| 7.18    |
| 5   | Ivanov (Iva)                | 3.28| 3.57| 3.47| 3.68| 3.52| 3.49| 3.45| 3.56| 3.75| 3.54| 3.49| 3.36| 3.51    |
| 6   | Hargreaves-74 (Harg)        | 4.86| 4.76| 4.88| 4.63| 4.22| 3.93| 4.08| 4.46| 4.89| 5.04| 4.97| 4.89| 4.63    |
| 7   | Penman (Pen)                | 4.47| 4.59| 4.90| 4.89| 4.78| 4.49| 4.64| 5.12| 5.20| 5.10| 4.88| 4.50| 4.80    |
| 8   | Modified Penman-Montieth (P-M)| 3.86| 3.94| 4.16| 4.15| 4.01| 3.71| 3.83| 4.29| 4.46| 4.39| 4.19| 3.87| 4.07    |
Figure 3. Comparison of evapotranspiration results for all methods (Bora Station)

The baseline monthly ETp values calculated for each station are presented in Figures 1 to 3 and Tables 3 to 5. Based on the method used, the largest ETp value was for the Makkink Method and the smallest was for the Ivanov Method. Taking into account the resulting monthly ETp patterns, the Makkink Method and FAO graphs are similar to each other, while the other methods have similar graph patterns among themselves. This condition occurred for all three climatology stations. When the obtained calculation results were made to relate to the height of the location, it was found that the ETp value tended to decrease with the height of the location, especially the ETp from estimation methods that only base the calculation on temperature data, such as the Ivanov Method. This fact is related to a decrease in temperature with increasing altitude from the surface of the sea.

3.2. Evapotranspiration Calculation Results with Temperature Increase

Table 6. Results of evapotranspiration calculations with temperature increase
Figure 4. Percentage of temperature increase, ETo (Singkoyo Station)

Figure 5. Percentage of temperature increase, ETo (Kulawi/Boladangko Station)

Figure 6. Percentage of temperature increase, ETo (Bora Station)
The percentage change in ETp, as a response to the temperature change calculated using eight different calculation methods, generally showed that the Blaney-Criddle Method provided the largest response, followed by the Penman-Montieth, Modified Penman, Thornthwaite, Hargreaves 74, FAO, and Ivanov methods. The smallest response was shown by ETp calculated using the Makkink Method.

The relative sensitivity of the ETp calculation method to temperature changes varies by place and is greatly influenced by the initial value of the variable before the change is applied. At Singkoyo Station, the Blaney-Criddle Method with an increase in temperature of 3 °C resulted in a change in ETp of 37.26%, while the Makkink Method only resulted in a change of 4.20%. At Kulawi Station, with the same temperature rise for the Blaney-Criddle Method, this resulted in a change in ETp of 37.26%, while the Makkink Method only resulted in a change of 2.83%. At the Bora station, with an increase in temperature of 3 °C, the Blaney-Criddle Method resulted in a change in ETp of 37.26%, while the Makkink Method only resulted in a change of ETp of 3.04%.

Based on the analysis results as shown in Table 6 and Figures 4-6, it can be seen that the Thornthwaite and Blaney-Criddle methods are the most sensitive to temperature changes, followed by the Penman-Montieth, Ivanov, Hargreaves 74, and Modified Penman methods, while the FAO and Makkink methods only showed a relatively small sensitivity.

From the analysis results, there is a mixed picture of the effect of temperature increase on ETp, depending on the method chosen in the analysis. In addition, the results of the analysis also depend on the location (station), which is related to the value of the variable before the temperature change is applied.

4. Conclusion
The analysis results lead to various conclusions on the effect of climate change on ETp, depending on the utilized ETp calculation method, the data needed for the calculation, as well as the structural form of the equation. The Thornthwaite and Blaney-Criddle methods are the most sensitive to temperature changes, followed by the Penman-Montieth, Ivanov, Hargreaves 74, and Modified Penman methods, while the FAO and Makkink methods show relatively little sensitivity.

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