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*Research Article*

# Evapotranspiration of Indonesian Tropical Area

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## Abstract

Indonesia is an archipelago country with a tropical climate. The region of Indonesia is quite large and located between two continents (Asia and Australia) and between two oceans (Indian and Pacific), making the territory of Indonesia has a unique climate pattern. One of the climate variables that quite important to be studied in this chapter is evapotranspiration. The Thornthwaite method was used to estimate potential evapotranspiration based on average air temperature. The relationships between evapotranspiration, precipitation, and elevation were then examined. Besides, temperature variations that affect climate patterns between monsoonal and equatorial regions were compared, between the mainland and small islands, and between mountain and coastal area. The impact of global warming was also examined on the climate and potential evapotranspiration of the Indonesian region. Data analysis showed that evapotranspiration correlates weakly with precipitation, and the contrary, the evapotranspiration correlates strongly with elevation, with correlation indices of 0.02 and 0.89, respectively. The study confirmed that air temperature is the primary controlling variable of the evapotranspiration in this very heterogeneous landscape. Under a global temperature increase of 1.5 °C above the pre-industrialized year (1765), the evapotranspiration is expected to increase in a range from 4.8 to 11.1%. In general, the excess of water to restore soil moisture in the future tends to decrease, i.e., drier.

**Keywords:** equatorial, monsoonal, mainland, precipitation, a small island, Thornthwaite

## 1. Introduction

Evapotranspiration is a necessary process or stage in a hydrological cycle. This process is a combination of evaporation and transpiration. Evaporation is the process of changing molecules in a liquid state spontaneously into a gas (water vapor). The method of exchanging water molecules on the earth's surface into units of water vapor in the atmosphere occurs through heat power, namely the sunlight energy. Thus, evaporation can only take place if there is sufficient energy that allows water to change to vapor or gas. Transpiration is a process of evaporation that takes place in living tissue and is influenced by plant physiology. Plants release moisture through a process called transpiration. Most transpiration takes place through stomata and occurs when plants open their stomata's to take $CO_2$ from the air for photosynthesis. More than 20% of the water carried by roots released into the atmosphere as water vapor. For high-level plants, 90% of the transpiration process occurs through stomata in the leaves (Thornthwaite, 1948; Lestari, 2006).

Studying the characteristics of hydrological components can help in water resources management. As one of the main elements of hydrology, evapotranspiration is very important to be accurately assessed for planning water use efficiency in the agricultural sector, environmental and ecosystem maintenance, and broader water resources management (Lang et al., 2012). Estimating evapotranspiration values consistently and reliably is needed to determine water balance in the area for more effective and efficient water resources management. The difference between precipitation on the earth's surface and evapotranspiration is reserve water that can be utilized by humans, both in the form of surface water and groundwater. It is impractical to separate evapotranspiration into a component of evaporation and transpiration for general water balance analyses. Therefore, several empirical methods have been developed to estimate the potential of evapotranspiration as a combination of evaporation and transpiration, which is generally influenced by three main factors, including meteorology, plant physiology, and surface soil characteristics.

Indonesia is a vast archipelago country consisting of 17,504 big and small islands (Rosenberry et al., 2007), spreading in a tropical region between 6° North Latitude and 11° South Latitude, and 95° East Longitude to 141° East Longitude. It is in the Inter-Tropical Convergence Zone (ITCZ) area, with a low-pressure center due to intensive sunlight warming. It gets relatively constant sunshine throughout the year. The temperature and humidity are relatively uniform throughout the year because this country is continually surrounded by warm ocean water. The variation in temperature occurs mostly due to topographic influence. This heating process causes a very high evaporation rate. Its location between Asia and Australia, and between the Indian Ocean and the Pacific Ocean, affects seasonal precipitation patterns of this region. In particular, the monsoonal winds cause a significant part of Indonesia to experience two main seasons, namely dry season and wet or rainy season. Besides, sizeable atmospheric circulation acting in the Pacific Ocean, namely El Niño Southern Oscillation (ENSO), could cause inter-annual climate variations of extreme events in Indonesia.

Because Indonesia is dispersed widely, variations in climate characteristics can occur in the region. Several factors cause changes, including the geographical position that affects the main climatic patterns of the area, topography, and land cover that could affect climate locally. Estimating evapotranspiration over the whole region will help to overview the hydrological conditions of the region. There are many available methods for estimating evapotranspiration. The most direct ways to measure evapotranspiration are panned evaporation and lysimeter. For spatial analysis purposes, empirical methods are commonly used. There are temperature-based practical methods such as Thornthwaite, Blaney-Criddle, and Hamon methods, and radiation-based or energy-balance methods such as Turc, Penman-Monteith, Makkink, Priestley-Taylor, and Priestley-Taylor methods (Lang et al., 2012; Tukiman et al., 2012). These methods vary from a simple one that requires very few variables, such as the Thornthwaite method, to a complex one that needs many variables, such as the Penman method. The selection of the ways to be used depends mainly on the availability of data.

This study aims to explain the estimation of potential evapotranspiration from several stations distributed throughout Indonesia, representing regions with different precipitation types. It will also differentiate between the mainland and small-island and between mountain and coastal types, to give better understand factors influencing the diversity of evapotranspiration in Indonesia's tropical region. The impact of global warming on evapotranspiration will also be discussed to understand future evapotranspiration and how it may affect water resources in many places in Indonesia.

## 2. Methods

### *2.1. Data Sources*

Raw data for analysis in this study come from the Meteorological, Climatological, and Geophysical Agency (BMKG). BMKG is a national agency that has a government mandate to carry out all works in the fields of Meteorology, Climatology and Geophysics and air quality, including to collect, manage and publish data related to meteorology, climatology, and geophysics that take place in Indonesia, and to conduct future predictions and projections. BMKG provides online data services from several stations distributed throughout Indonesia, in particular, general-purpose climate data such as daily precipitation (mm) and air temperature (°C). This institution's website can be found at www.bmkg.go.id.

## 2.2. *Data Type*

The data used in this study are data on average daily air temperature and average daily precipitation data. These are time series recorded data from 1990 to 2017, although there are several years for which data are partially missing. These data come from twenty-two stations that represent the territory of Indonesia from region I to region V (**Table 1**). The distribution of the 22 stations over the country can be seen in **Figure 1**. Selected stations on the island of Java are relatively more than other islands because this island is the most populous in Indonesia, with a population density of approximately 21 thousand people / km² (BPS, 2015). Evapotranspiration analysis concerning the availability of water resources in Java is relatively more strategic compared to other islands. The number of stations reviewed in Java is ten stations. Two stations were selected for each of the other main islands to represent mountainous and coastal regions.

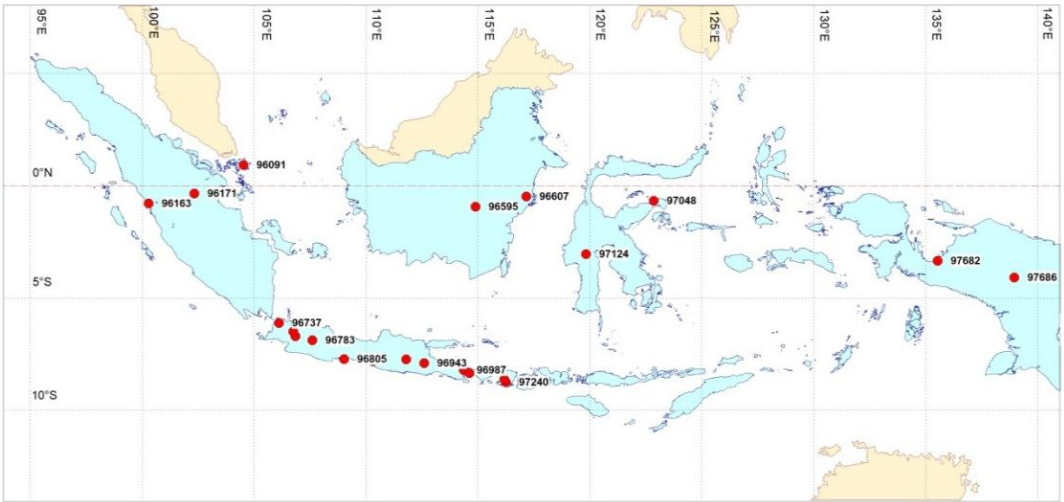


**Figure 1.** Several climate monitoring stations scattered throughout the Indonesian archipelago

The station selection location is part of the data to be analyzed. In addition to the elevation where the measurement station located, the location of the station will study, namely, stations located in the monsoonal or tropical areas, in the mainland or small island areas, and in the mountainous or coastal regions. The characteristics of these areas have different morphological and environmental forms, which will undoubtedly affect the results of evapotranspiration.

## 2.3. *Method of Calculating Evapotranspiration*

In this study, the evapotranspiration is estimated using the Thornthwaite method. This method relies mainly on average monthly air temperature (Xu and Singh, 2001). This variable is one of few variables that are always measured by BMKG, that make this method as a potential choice. This method has a weakness that can significantly underestimate the amplitude of seasonal fluctuation (Dagg and Blackie, 1970). However, this seasonal fluctuation is insignificant in the tropical region such as Indonesia, where solar radiation is homogeneous and relatively fixed throughout the year (Murtiono, 2009). This fact is supported by a study conducted by Toriman et al. (2009), which states that the Thornthwaite method is the most suitable method for estimating evapotranspiration values in North Kedah, Malaysia (Toriman et al., 2009) that also has a tropical climate. Research by Rosenberryy et al. (2007) in Mirror Lake corroborates this justification that methods that require measurement of solar radiation and air temperature are not much better than methods that only need air temperature measurements (Rosenberry et al., 2007).

Potential evapotranspiration equation of the Thornthwaite method is formulated with equation (1) the following:

$$ET_{monthly} = 1.62\left[\frac{10\,T_m}{I}\right]^{\alpha} \qquad (1)$$

Where $T_m$ is the average monthly temperature, and $I$ am the sun radiation index calculated by equation (2) and equation (3):

$$I = \sum_{m=1}^{12}\left(\frac{T_m}{5}\right)^{1.514} \qquad (2)$$

$$\alpha = (675 \times 10^{-9} \times I^3) - (771 \times 10^{-7} \times I^2) + (1792 \times 10^{-5} \times I) + (492 \times 10^{-3}) \qquad (3)$$

After getting the $_{monthly}$ value from the calculation using the equation (1) then the $_{monthly}$ value is then corrected using a correction factor adjusted to the latitude position of the research location with the following equation (4):

$$ET_{correction} = ET_{monthly} \times \text{correction factor} \quad (4)$$

The correction factor is available in Thornthwaite (1948), page 93.

**Table 1.** The meteorological/climatological/geophysical stations that used in data analysis

| Station Name | Number Station | Region | Province | Type of Precipitation | Type of Island |
|---|---|---|---|---|---|
| Kijang[1] | 96091 | I | Kep. Riau | Equatorial | S |
| Minangkabau[1] | 96163 | I | Sum. Barat | Equatorial | M |
| Japura[1] | 96171 | I | Riau | Equatorial | M |
| Serang[1] | 96737 | II | Banten | Monsoonal | M |
| Maritim Tj Priok[1] | 96741 | II | DKI Jakarta | Monsoonal | M |
| Citeko[1] | 96751 | II | Jawa Barat | Monsoonal | M |
| Bogor[2] | 96753 | II | Jawa Barat | Monsoonal | M |
| Bandung[3] | 96783 | II | Jawa Barat | Monsoonal | M |
| Cilacap[1] | 96805 | II | Jawa Tengah | Monsoonal | M |
| Yogyakarta[3] | 96855 | II | Yogyakarta | Monsoonal | M |
| Beringin[1] | 96595 | III | Kal. Tengah | Equatorial | M |
| Temindung[1] | 96607 | III | Kal. Tengah | Equatorial | M |
| Malang[2] | 96943 | III | Jawa Timur | Monsoonal | M |
| Sawahan[3] | 96975 | III | Jawa Timur | Monsoonal | M |
| Banyuwangi[1] | 96987 | III | Jawa Timur | Monsoonal | M |
| Jembrana[2] | 97236 | III | Bali | Monsoonal | S |
| Bandara Int. Lombok[1] | 97240 | III | NTB | Monsoonal | S |
| Lombok Barat[2] | 97242 | III | NTB | Monsoonal | S |
| Djalaluddin[1] | 97048 | IV | Sul. Utara | Local | M |
| Pongtiku[1] | 97124 | IV | Sul. Selatan | Monsoonal | M |
| Moanamani[1] | 97682 | V | Papua | Equatorial | M |
| Wamena Jaya Wijaya[1] | 97686 | V | Papua | Equatorial | M |

(1) Meteorology station; (2) Climatology station; (3) Geophysical station; M = Mainland; S = Small Island. Regional division is for administrative and management purpose.

## 2.4. *Estimating Impact of Global Warming*

The increased concentration of greenhouse gasses leads to global warming that causes changes in regional as well as local climate variables such as temperature, cloud cover, precipitation, air humidity, and wind patterns. The global warming impact was calculated based on an increased global temperature by 1.5 °C relative to the pre-industrialized era (the year 1765). Based on greenhouse gas concentration scenarios, i.e. Representative Concentration Pathways (RCPs) that has been adopted by the Intergovernmental Panel for Climate Change (IPCC) for its Fifth Assessment Report (Collins et al., 2013), this degree of warming has been projected to take place around 2030s (Meinshausen et al., 2011). We used the average of 18 coupled Atmosphere-Ocean General Circulation Models (AOGCMs) output archived in Coupled Model Intercomparison Project (CMIP) that are contained in the MAGICC/ SCHENGEN version 5.3 to obtain changes in air temperature and precipitation variables (Wigley, 2008). For the baseline, we used the existing 1990-2017 climate data set from BMKG (see **Table 1**).

## 3. Results and Discussion

### *3.1. Precipitation Characteristic of Indonesian Tropical Area*

Indonesia's geographical location with a wide range of regions causes a difference in the amount of precipitation between one part and another. Tjasyono (2004) divides the type of precipitation pattern in Indonesia based on the distribution of monthly average rainfall into three groups, namely areas with monsoonal types, equatorial types, and local types (**Figure 2**, see **Table 1**) (Tjasyono, 2004).

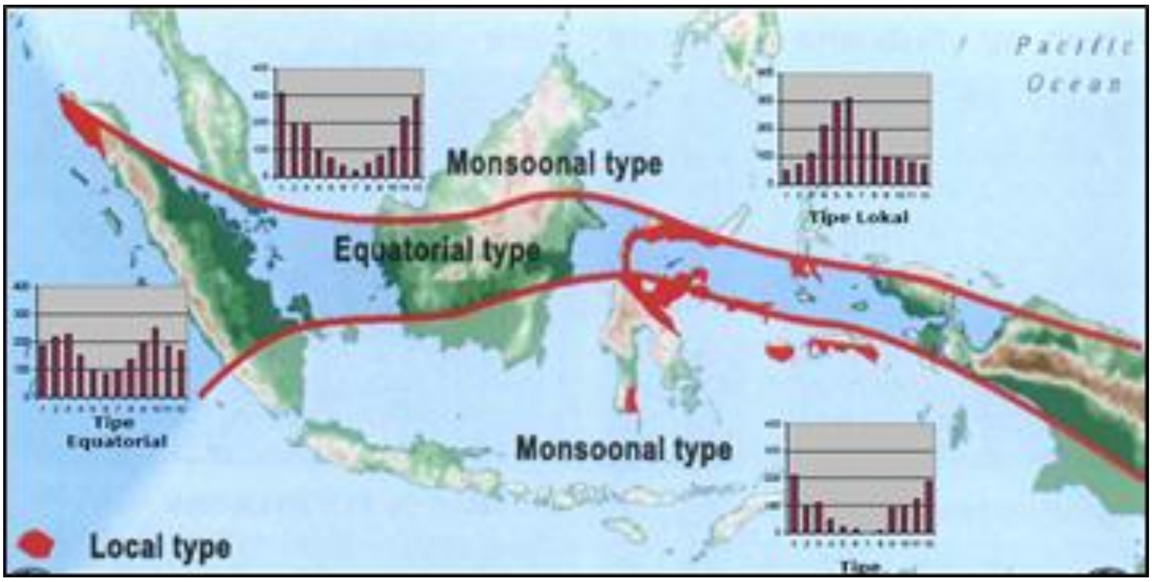


**Figure 2.** Indonesian territory based on monthly average precipitation distribution (Adapted from Tjasyono, 2004)

The first group is an area with monsoonal precipitation patterns. This region has a clear enough difference between the period of the rainy season and the dry season period, which then grouped in the Season Zone. Mohr (in Lakitan, 1994) provides a classification of the division of months within one year based on the relationship between evaporation and the amount of precipitation into three classes. The situation is called a wet month if rainfall is more than 100 mm per month, called a humid month if rainfall ranges from 60-100 mm per month, and is called a dry month if rain is less than 60 mm per month (Lakitan, 1994; Irianti et al., 2017). The rainy season period occurred if precipitation above 100 mm per month. Monsoonal patterns are also characterized by the type of precipitation that is unimodal (one peak of the rainy season), DJF (December-January-February), the rainy season, and JJA (June-July-August) dry season. Examples of locations with monsoonal precipitation patterns are the Bandung Geophysics Station with station code 96783 (**Figure 3**, left).

The second group is an area with equatorial precipitation patterns. This area has a monthly bimodal rain distribution with two peaks in the maximum rainy season and almost all the year in the rainy season criteria. Equatorial patterns do characterize by the type of precipitation with a bimodal form (two peaks of rainfall), which usually occur around March and October. Examples of locations with equatorial precipitation patterns are Kijang Climatology Station with station code 96091 (**Figure 3**, center).

The third group is an area with local precipitation patterns. This area has a monthly precipitation distribution in contrast to monsoonal precipitation patterns. Local patterns form a unimodal rain pattern (one peak of rain) but in the opposite shape of the monsoonal rain pattern. Areas that have this type of local precipitation are generally of typical semi-arid regions where rain falls in less than five months. An example of a regional precipitation pattern is Djalaludin Climatology Station with station code 97048 (**Figure 3**, right).

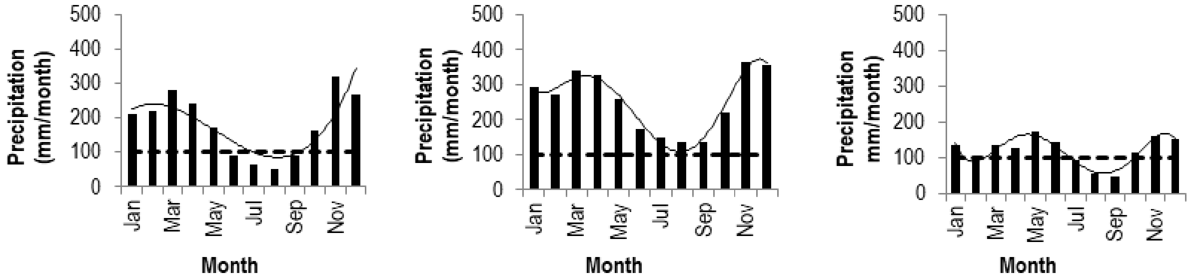


**Figure 3**. Precipitation type in Indonesia Tropical Region: Monsoonal (Left), Equatorial (Center), and Local (Right). Data were processed from Bandung Geophysics Station, Kijang Climatological Station, and Djalaluddin Climatological Station, respectively.

Understanding rain patterns are significant to be able to manage water resources, especially areas where the water source is very dependent on rainwater. Some regions in Indonesia that depend on rain to meet the water needs of the community include Riau Islands Province, where the Kijang Station located. This dependence caused by the land surface characteristics of the island is dominated by geological types such as granite, which is entirely impermeable so that rainwater overflows as runoff.

**Table 2.** The estimation of potential evapotranspiration

| No. | Station Name | ET (mm/year) | P (mm/year) | (P-ET) (mm/year) | Altitude m (amsl)(4) |
|---|---|---|---|---|---|
| 1 | Kijang(1) | 1658 | 3198 | 1539 | 18 |
| 2 | Minangkabau(1) | 1663 | 4139 | 2476 | 6 |
| 3 | Japura(1) | 1704 | 2296 | 592 | 19 |
| 4 | Serang(1) | 1730 | 1590 | -139 | 100 |
| 5 | Maritim Tanjung Priok(1) | 2159 | 1791 | -368 | 3 |
| 6 | Citeko(1) | 997 | 3208 | 2210 | 920 |
| 7 | Bogor(2) | 1523 | 3846 | 2324 | 207 |
| 8 | Bandung(3) | 1194 | 2170 | 976 | 791 |
| 9 | Cilacap(1) | 1779 | 3480 | 1701 | 8 |
| 10 | Yogyakarta(3) | 1612 | 2031 | 419 | 153 |
| 11 | Beringin(1) | 1749 | 3022 | 1272 | 31 |
| 12 | Temindung(1) | 1839 | 2104 | 265 | 3 |
| 13 | Malang(2) | 1203 | 1871 | 668 | 590 |
| 14 | Sawahan(3) | 1247 | 2932 | 1686 | 835 |
| 15 | Banyuwangi(1) | 1874 | 1578 | -296 | 52 |
| 16 | Jembrana(2) | 1682 | 2001 | 319 | 25 |
| 17 | Bandara Internasional Lombok(1) | 1657 | 1724 | 67 | 92 |
| 18 | Lombok Barat(2) | 1396 | 1915 | 519 | 55 |
| 19 | Djalaluddin(1) | 1768 | 1424 | -345 | 33 |
| 20 | Pongtiku(1) | 1108 | 2639 | 1531 | 829 |
| 21 | Moanamani(1) | 1844 | 4170 | 2326 | 3 |
| 22 | Wamena Jaya Wijaya(1) | 904 | 1806 | 901 | 1655 |

(1) Meteorological station; (2) Climatological station; (3) Geophysical station
(4) amsl = above mean sea-level

## 3.2. *Analysis of Evapotranspiration in Indonesian Tropical Area*

Evapotranspiration analysis in this study uses the Thornthwaite method approach based on average air temperature. Therefore, reviewing changes in the air temperature in different regions will provide information on the estimated potential evapotranspiration that can represent the Indonesian area. **Table 2** is the result of calculating the estimated potential evapotranspiration in many areas of Indonesia. The average annual precipitation value also figured in the analysis. P-ET is the difference between precipitation and the average yearly potential evapotranspiration. Negative values of (P-ET) indicate that the amount of rainfall cannot increase the potential for water needs from areas covered by vegetation.

Conversely, the positive value of P-ET indicates that there is an excess amount of water for a specified period of 1 year to restore soil moisture (Murtiono, 2009). The difference between precipitation and evapotranspiration (P-ET) can also be used as the primary control of the availability of water in rivers and aquifers (Teuling, 2018). Thus, the value of precipitation can indirectly affect the potential amount of evapotranspiration (Trenberth and Shea, 2005). However, the results show that rainfall and evapotranspiration have a fragile relationship with the correlation coefficient of 0.02 (**Figure 4**). The results also shows that precipitation and evapotranspiration do not affect each other even though the amount of evapotranspiration becomes an important factor in the clouds formation, which causes precipitation.

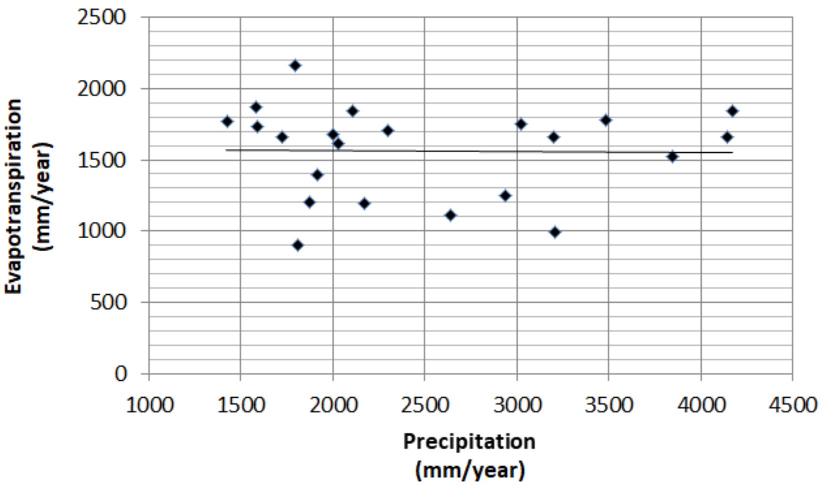


**Figure 4**. Correlation between precipitation and evapotranspiration

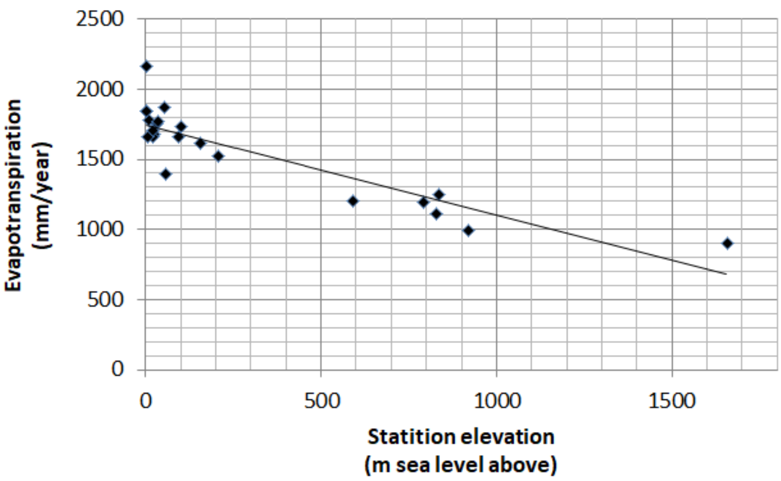


**Figure 5**. Correlation between evapotranspiration and elevation

On the contrary, the evapotranspiration has a robust negative correlation with the station elevation. Their correlation coefficient is 0.89. **Figure 5** shows that the higher the height of the measurement station, the lower the evapotranspiration value. Because evapotranspiration using the Thornthwaite method based on air temperature, it can be said that the higher the elevation of a place, the lower the air temperature. Mountainous areas are relatively closed in denser vegetation than lowland or coastal regions. So, it can be distinguished that air temperatures in the mountains are comparatively colder than on tidal. Previous studies have shown that vegetation, especially forests have a substantial impact and is a significant factor in influencing evapotranspiration, although plant species will provide different evapotranspiration values (Teuling, 2018; Gong et al., 2017).

Some researchers acknowledge that 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. Land degradation also causes more runoff or surface flow than infiltration, and the increasing air temperature and surface flow will increase potential evapotranspiration (Karimi et al., 2017; Rushayati et al., 2018; Ping and Liu, 2018). In contrast, researchers also found that the deforestation process can also reduce evapotranspiration because of reduced transpiration by plants (Snyman, 2001; Feddema and Freire, 2001; Zeng and Yang, 2008; Li et al., 2013; Gong, 2017; Karimi et al., 2017; Rushayati et al., 2018; Ping and Liu, 2018). Further studies needed regarding the estimation of potential evapotranspiration at the same elevation as different vegetation and the corresponding vegetation at different altitudes. This condition is quite interesting to carry out reforestation policies, especially on critical lands. With accurate calculations, reforestation is expected to be still able to provide water balance in the area.

In addition to elevation and vegetation, the characteristics of Indonesia's tropical regions show differences in the value of the surrounding air temperature. **Figure 6** shows how the average air temperature difference is measured based on the different character of areas in the tropical parts of Indonesia. Areas with the type of equatorial precipitation have average air temperatures that are relatively higher than those with monsoonal precipitation types. Cities located on small islands have relatively higher air temperatures than the mainland. And the coastal regions have relatively higher air temperatures than mountainous regions.

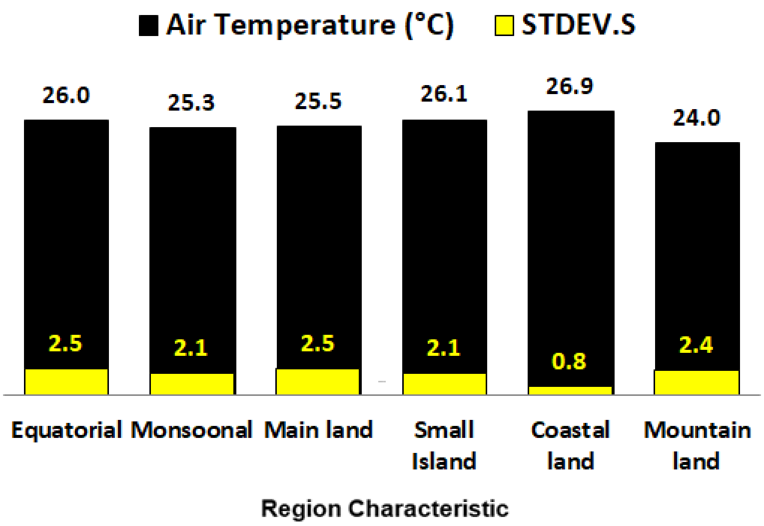


**Figure 6**. Comparison of air temperature between tropical areas in Indonesia

Of the three different characteristics areas, it can be said that evapotranspiration is a complicated process. Sun radiation, water vapor pressure, wind speed, soil moisture condition, vegetation physiology, and topography provide variation in evapotranspiration values. This complicated process does not result in a consensus on the impact of land use or land cover changes on the estimation of potential evapotranspiration in an area. However, Tian et al. (2015) still believe that the function of vegetation is an important factor that influences evapotranspiration (Tian et al., 2015).

## 3.3. Global Warming Impact on Evapotranspiration

The results show that an increase in global temperature as much as 1.5°C could increase the temperature in tropical region of Indonesian from 1.20°C to 1.55°C with an average 1.33°C, which indicates that the rate of warming is at a similar or slightly lower than the rate of global warming. However, this increase in global temperature does not affect average annual precipitation volume. All stations show very small or insignificant changes in annual precipitation that range from -0.01% to 0.02% (**Table 3**).

**Table 3**. Projected value of climate variables under global warming of 1.5 °C above the pre-industrialized (the year 1765), and changes in temperature, precipitation, and evapotranspiration relative to baseline (1990-2017)

| | Station Name | Projected Value | | | | Projected Change | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | T (°C) | P (mm/year) | ET (mm/year) | P-ET (mm/year) | ΔT (%) | ΔP (%) | ΔET (%) | Δ(P-ET) (%) |
| 1 | Kijang(1) | 27.2 | 3198 | 1814 | 1383 | 2.6 | 0.00 | 9.4 | -10.1 |
| 2 | Minangkabau(1) | 27.3 | 4139 | 1828 | 2311 | 2.7 | 0.00 | 9.9 | -6.6 |
| 3 | Japura(1) | 27.5 | 2296 | 1877 | 419 | 2.7 | 0.00 | 10.2 | -29.3 |
| 4 | Serang(1) | 27.5 | 1590 | 1894 | -304 | 2.5 | -0.02 | 9.5 | 118.5 |
| 5 | Maritim Tanjung Priok(1) | 29.1 | 1791 | 2398 | -607 | 2.4 | -0.01 | 11.1 | 65.1 |
| 6 | Citeko(1) | 21.9 | 3207 | 1049 | 2158 | 3.2 | -0.01 | 5.2 | -2.4 |
| 7 | Bogor(2) | 26.5 | 3846 | 1653 | 2193 | 2.6 | -0.01 | 8.5 | -5.6 |
| 8 | Bandung(3) | 24.1 | 2170 | 1272 | 898 | 2.9 | -0.01 | 6.6 | -8.1 |
| 9 | Cilacap(1) | 27.7 | 3480 | 1947 | 1533 | 2.5 | 0.00 | 9.4 | -9.9 |
| 10 | Yogyakarta(3) | 26.9 | 2031 | 1754 | 277 | 2.5 | 0.00 | 8.8 | -33.9 |
| 11 | Beringin(1) | 27.7 | 3022 | 1933 | 1089 | 2.7 | 0.01 | 10.5 | -14.4 |
| 12 | Temindung(1) | 28.1 | 2105 | 2033 | 71 | 2.6 | 0.01 | 10.6 | -73.1 |
| 13 | Malang(2) | 24.2 | 1871 | 1283 | 588 | 2.9 | 0.00 | 6.7 | -12.0 |
| 14 | Sawahan(3) | 24.6 | 2932 | 1333 | 1599 | 2.8 | 0.00 | 6.9 | -5.1 |
| 15 | Banyuwangi(1) | 28.1 | 1578 | 2062 | -484 | 2.5 | 0.00 | 10.0 | 63.7 |
| 16 | Jembrana(2) | 27.3 | 2001 | 1837 | 163 | 2.5 | 0.00 | 9.3 | -48.8 |
| 17 | Bandara Int. Lombok(1) | 27.2 | 1724 | 1810 | -86 | 2.6 | 0.00 | 9.3 | -228.6 |
| 18 | Lombok Barat(2) | 25.7 | 1915 | 1508 | 407 | 2.7 | 0.00 | 8.0 | -21.6 |
| 19 | Djalaluddin(1) | 27.7 | 1424 | 1938 | -514 | 2.5 | 0.02 | 9.6 | 49.1 |
| 20 | Pongtiku(1) | 23.3 | 2639 | 1176 | 1463 | 3.0 | 0.01 | 6.1 | -4.4 |
| 21 | Moanamani(1) | 28.0 | 4170 | 2030 | 2140 | 2.5 | 0.01 | 10.1 | -8.0 |
| 22 | Wamena Jaya Wijaya(1) | 20.5 | 1806 | 947 | 859 | 3.7 | 0.02 | 4.8 | -4.8 |

(1) Meteorological station; (2) Climatological station; (3) Geophysical station

Warmer air temperatures increase the rate of evaporation, which is reflected in the positive change in evapotranspiration (**Table 3**). Therefore, warming at a higher rate than the rate of precipitation could cause lower differences between rainfall and potential evaporation. This condition leads to a smaller volume of excess water to moist soil. In other words, the land would become drier. This change in the amount of soil moist should be considered and anticipated because it may affect the water availability and supply for domestic use. It may also affect the productivity of water-related sectors, such as agriculture and aquaculture.

## 4. Conclusion

This study shows that elevation is an essential factor in controlling evapotranspiration in the Indonesian tropical regions, as estimated using the Thornthwaite method. This is because of a strong relationship between altitude and air temperature. Besides, evapotranspiration in areas with equatorial precipitation type is generally higher than the one with monsoonal precipitation type. Evapotranspiration in the mainland region is higher than the one in small island regions, and the coastal areas have higher evapotranspiration than mountainous regions. This study also shows that global warming has a minimal effect in the amount of annual precipitation, but could increase the temperature of the Indonesian area at a similar rate with the increase of global temperatures, which leads to drier soil condition or decreasing water availability. This information is precious for policy-making in water resources management, both locally and nationally. By knowing the average estimates of potential evapotranspiration in the tropical region of Indonesia or other areas with similar climate, policy, or technology interventions can be provided to manage water resources sustainably. Besides, understanding the impact of global warming on evapotranspiration is very beneficial for better preparation in anticipating the potential increasing pressure in the development of water-dependent sectors.

## Acknowledgments

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