

Potential Evapotranspiration in Merapi Aquifer System

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Abstract

Temperature variation due to climate change can give greatest impact on potential evapotranspiration. Increase of temperature in Yogyakarta Special Region can increase potential evapotranspiration. It is necessary to study potential evapotranspiration as one of indication impact of climate change to its potential evapotranspiration. Potential evapotranspiration (PET) can be estimated applying Hargreaves and Samani (1982) that requires limited meteorological parameter. Therefore, this research aims are: a) to analyze daily PET in 3 gauge station of Merapi Aquifer System, b) to analyze variation PET in the 3 gauge stations of Merapi Aquifer System.

The largest values of PET is in Barongan station, while the lowest is in Adisucipto station. It is probably because Adisucipto station is located in urban and crowded areas. PET values are mostly 1.98 mm/day in rainy season, while 1.67 mm/day in dry season. Mostly, the correlation coefficient is low in dry season for Pluyon, Barongan and Adisucipto stations suggesting that drier and warmer temperature due to climate change do not have large impact to PET. The 5-month moving average trend also confirm the relatively stable line of PET variation from January 2005 to December 2016 reflecting that climate change do not greatly impact on PET in Merapi Aquifer System.

Keywords:

potential evapotranspiration, climate change, Merapi Aquifer System

Introduction

Evapotranspiration is one of the most important component in water balance since it is together with rainfall and runoff controlling water distribution in Earth's surface (McCabe & Wood, 2006). Evapotranspiration is also linked surface energy balance and climate change. Climate change has greatest impact on evapotranspiration (Rim, 2009). Any variation in meteorological variables, i.e. temperatures, induced by climate change will impact on evapotranspiration (Huo, Dai, Feng, Kang, & Huang, 2013). Global warming would increase dry condition by increasing potential evapotranspiration, domestic animal on fragile and unstable ecosystems (Goyal, 2004).

Evapotranspiration can be estimated from in situ measurement, remote sensing data, and land surface model (Ahamed, Knight, Alam, Pauloo, & Melton, 2022). Traditional point-scale methods in estimating evapotranspiration can use meteorological station-based data (Barik, Hogue, Franz, & Kinoshita, 2016). Temperature, humidity, wind speed, solar radiation, pan evaporation are meteorological data that is commonly used to estimate evapotranspiration. Penman-Monteith (Allen, Pereira, Raes, & Smith, 1998) and Priestley Taylor (Priestley & Taylor, 1972) are using a lot of parameter of meteorological data, i.e. temperature, humidity, wind speed and solar radiation, to calculate evapotranspiration. It is difficult to have long-term meteorological data without missing data because of the meteorological equipment is broken particularly in developing country. Wind speed, solar radiation or pan evaporation is commonly unavailable within the dataset in case the meteorological equipment is broken. Moreover, Penman-Monteith requires aerodynamic resistance and surface resistance, while Priestley Taylor requires a function of environmental variables that depends on a lot of factor such as leaf area index and soil water availability (Sumnera & Jacobs, 2005). Most of them are difficult to provide it (Xua & Singh, 2005) so that it is needed to estimate evapotranspiration with simple method in developing country.

Hargreaves and Samani provides minimum climatological data to estimate evapotranspiration (G. H. Hargreaves & Samani, 1982). It uses temperatures data only and it also can be applied in tropical country (Srivastava, Sahoo, Raghuwanshi, & Chatterjee, 2018). This method can be applied to estimate evapotranspiration if the data required to calculate Penman-Monteith is not available (Barik et al., 2016). Hargreaves and Samani considers one of the simplest and accurate method to estimate potential evapotranspiration. It can be used to analyze climate change impact on potential evapotranspiration (Srivastava et al., 2018).

Urbanization greatly effects a whole process of hydrological cycle including effects on evapotranspiration (Ya, Youpeng, & Yi, 2012). Urbanization is an image of city radial expansion into its rural surroundings (Carlson & Arthur, 2000). Merapi Aquifer System is one of famous groundwater basin in Indonesia that experiences urban expansion in a lot of areas in this basin. Merapi Aquifer System (MAS) also has a complex and variation of landscape leading to variation in meteorological variables. Both variation of climatology and urbanization will impact on evapotranspiration in MAS. Therefore, the purpose of this paper are: a). to analyze traditional point-scale method of evapotranspiration in MAS applying Hargreaves and Samani (1982), b). to analyze the primary study of the condition of potential evapotranspiration in MAS, c). to analyze variation of maximum temperature with potential evapotranspiration as indication climate change impact on potential evapotranspiration.

Maximum temperature is used to correlate effect of climate change to potential evapotranspiration because maximum temperature effect on dry condition that can increase potential evapotranspiration.

Study Area

Merapi Aquifer System (MAS) is a groundwater basin that is located in Yogyakarta Special Region provinces. This province is approximately situated in the middle of Java Island. MAS has complex landscapes such as sea border in the south, top of merapi volcano in the north, graben in the south, karst valleys border in the east, and ancient volcano border in the west. This condition can give impact to variation of climatology condition. Based on average calculation from 5 rain gauges stations from 2005 to 2017, average daily rainfall is 7.79 mm in rainy season, while in dry season is 2.45 mm. Average daily maximum temperature is 25 °C and average daily minimum temperature is 24 °C.

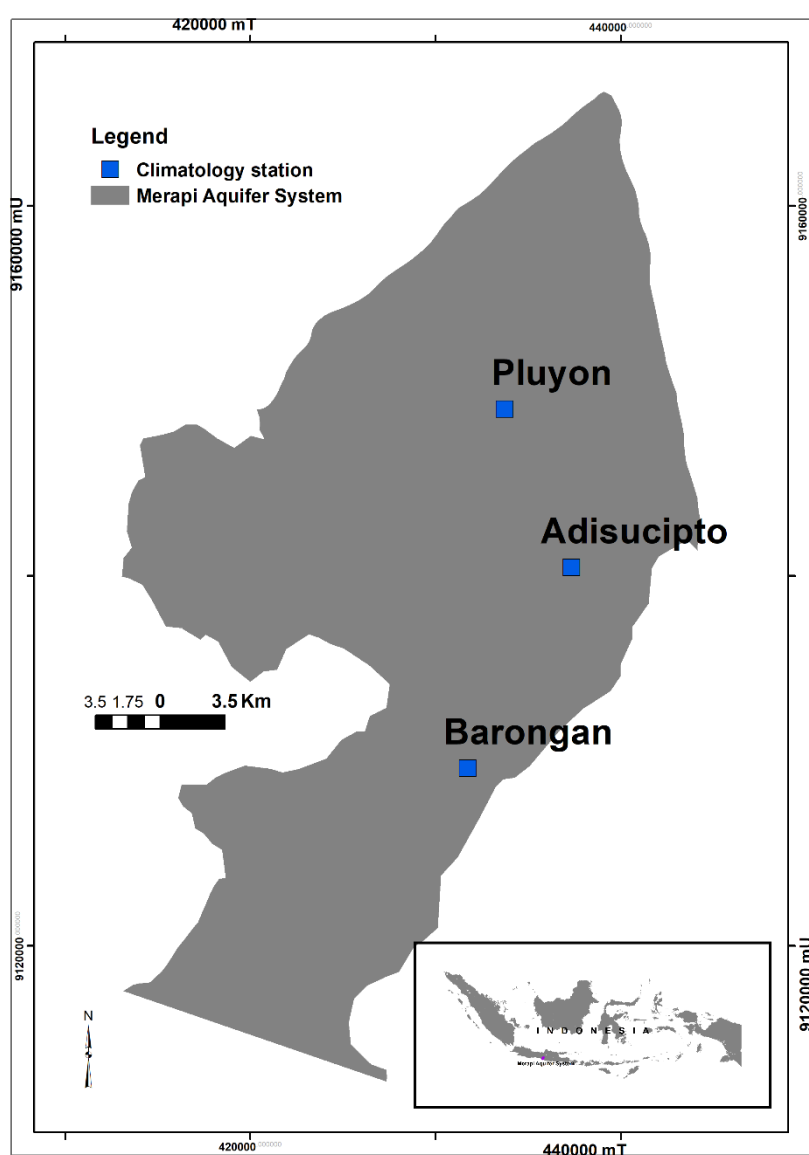


Figure 1. Merapi Aquifer System (MAS) location and climatology stations

Methods

Traditional point-scale method is applied to estimate potential evapotranspiration in Yogyakarta Special Region. Daily minimum and maximum temperature data is obtained from BBWS Opak Oyo. There are 3 stations with complete data available in this area (Figure 1). The missing data is estimated simply from correlation from other stations and one additional station to further analysis primary study of PET condition in this area. The one additional station is also not used to calculate potential evapotranspiration. Although this method is simple, but it is necessary to find out the primary knowledge of PET condition in the study area with a lot of missing data to further perform advance research. Potential evapotranspiration is estimated for 15 years periods from 1 January 2005 to 31 December 2016. It is because one year data sets on 2017 are missing for all stations owned by BBWS Opak Oyo. Hargreaves and Samani is applied to estimate potential evapotranspiration as express in Equation 1 to 3 (G. Hargreaves & Samani, 1985; G. H. Hargreaves & Samani, 1982; Srivastava et al., 2018).

$$PET = 0.0023 * R_a * [0.5 (T_{max} - T_{min}) + 17.8] \sqrt{(T_{max} - T_{min})} \quad \text{Equation 1}$$

where PET is potential evapotranspiration or reference crops evapotranspiration (Barik et al., 2016) in mm/day, R_a is extraterrestrial radiation in mm/day, T_{max} is maximum daily temperature in °C, T_{min} is minimum daily temperature in °C

$$R_a = \frac{1.440}{\pi} * (G_{sc} * d_r) * [\Psi_s \sin(\varphi) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(\psi_s)] \quad \text{Equation 2}$$

where G_{sc} is solar constanta (0.0820 MJ/m²/min), d_r is inverse relative distance from earth to sun, Ψ_s is sunset hour angle in radian, φ is latitude of location in rad, δ is solar declination in rad

$$d_r = 1 + 0.033 \cos \left[\frac{2\pi JD}{365} \right] \quad \text{Equation 3}$$

$$\delta = 0.409 \sin \left(2\pi \frac{JD}{365} - 1.39 \right) \quad \text{Equation 4}$$

where JD is day of the year

Precipitation and potential evapotranspiration is as a signal of climate change (Niel, Uytven, & Willems, 2019). Therefore, changes of potential evapotranspiration is explored in this

research as primary indication of climate change. Trend of PET is explored with 5-month moving average to indicate changes in PET during these years.

Result and Discussion

Point PET distribution is shown as histogram graph in Figure 2 in rainy and dry season separately from 1 January 2005 to 31 December 2016. The PET histogram of pluyon is skewed to the right side resulting the PET value tends to be high in daily basis in rainy season. The PET values are mostly 1.98 mm/day with a lot of frequency of PET more than 2.06 mm/day than less than 1.0 mm/day. PET histogram of Barongan is skewed to the left side with two peaks, but PET values are mostly 2.05 mm/day. The frequency of PET value are tends to have low value and mostly 1.18 to 1.67 mm/day. PET histogram of Adisucipto is skewed to the left side resulting PET values are mostly low in rainy season. PET values are more frequent to the value of ~1.83 mm/day. Daily PET is mostly more than 1.83 mm/day than more than 1.83 mm/day in Adisucipto. Compared to others stations, PET histogram of Adisucipto is not much skewed. Barongan station has largest PET values, followed by Pluyon then Adisucipto.

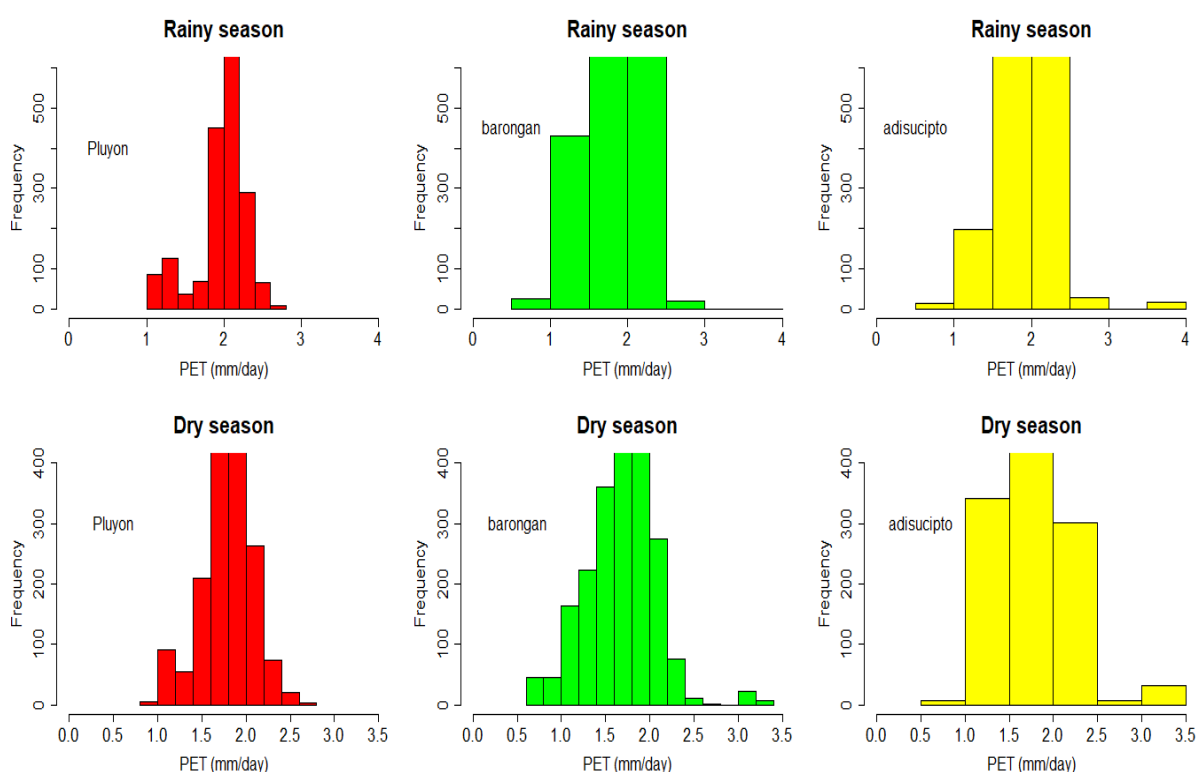


Figure 2. Histogram of potential evapotranspiration of three stations in rainy and dry season separately in Merapi Aquifer System in wet and dry period separately from 1 January 2005 to 31 December 2016

Point PET distribution of Pluyon is skewed to the right side resulting PET mostly high value in dry season from 1 January 2005 to 31 December 2016 (Figure 2). PET values are mostly ~1.67 mm/day. The frequency of PET values more than 1.67 mm/day is larger than less than

1.67 mm/day. PET histogram of Barongan is skewed to the left side resulting PET values less than 1.65 mm/day is more frequent compared to more than 1.65 mm/day. PET values of 1.65 mm/day is most frequent occurs in Barongan station. PET values of Adisucipto station are mostly 1.59 mm/day with the PET histogram is skewed to the right side. PET values of Barongan station and Pluyon stations is almost similar that only 0.02 mm/day of PET Pluyon is larger than PET values of Barongan. Adisucipto station has lowest PET values compared to two other stations.

The boxplot of point PET of 3 stations in Merapi Aquifer System are shown separately in rainy and dry seasons as Figure 3. Pluyon has lowest variability of daily PET, while Barongan has the largest variability of daily PET in rainy season. However, Adisucipto has a lot of outlier compared to others. It indicates there is a lot of daily temperature that is slightly different values as usual occasion. Daily PET is almost similar in dry season for three of the stations. There is no huge variability among them compared in rainy season. However, Adisucipto station has a lot of outlier as occurred in rainy season. It is probably because this station is located in urban area where daily temperature has a lot of fluctuation so that it influence daily PET.

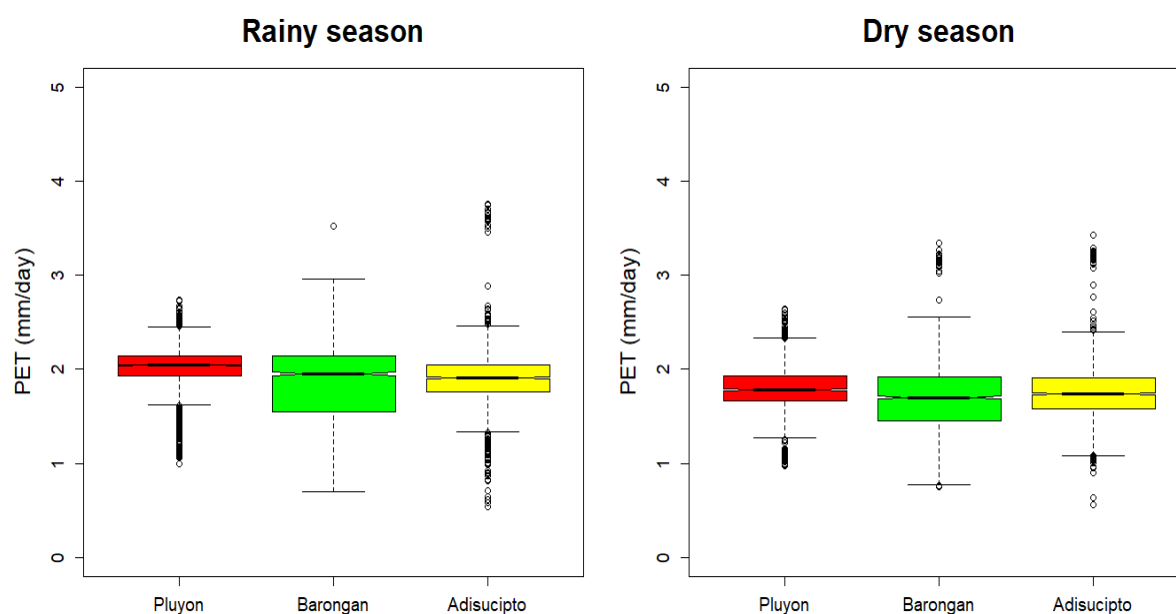


Figure 3. Boxplot of daily PET in three stations in Merapi Aquifer System in wet and dry period separately from 1 January 2005 to 31 December 2016

Barongan station has highest correlation coefficient between daily maximum temperature with potential evapotranspiration in rainy season (Figure 4), while Pluyon station has the lowest correlation coefficient. The values of correlation of coefficient between maximum temperature and potential evapotranspiration for Barongan, Adisucipto and Pluyon continuously are 0.88; 0.51; and 0.10. Barongan station has highest correlation coefficient probably because this station is located in low land and sub urban areas (Mazrooei, Reitz, Wang, & Sankarasubramanian, 2021). Variation of temperature is not as high as

temperature variation in Adisucipto where is located in urban and low land areas. Temperature variation easily can swift in urban areas while potential evapotranspiration is static due to a lot of concrete impermeable surfaces in urban. It is an opposite with high elevation and remote areas of Pluyon station since temperature variation does not fluctuates dramatically because of a lot of vegetation (Zhou et al., 2022).

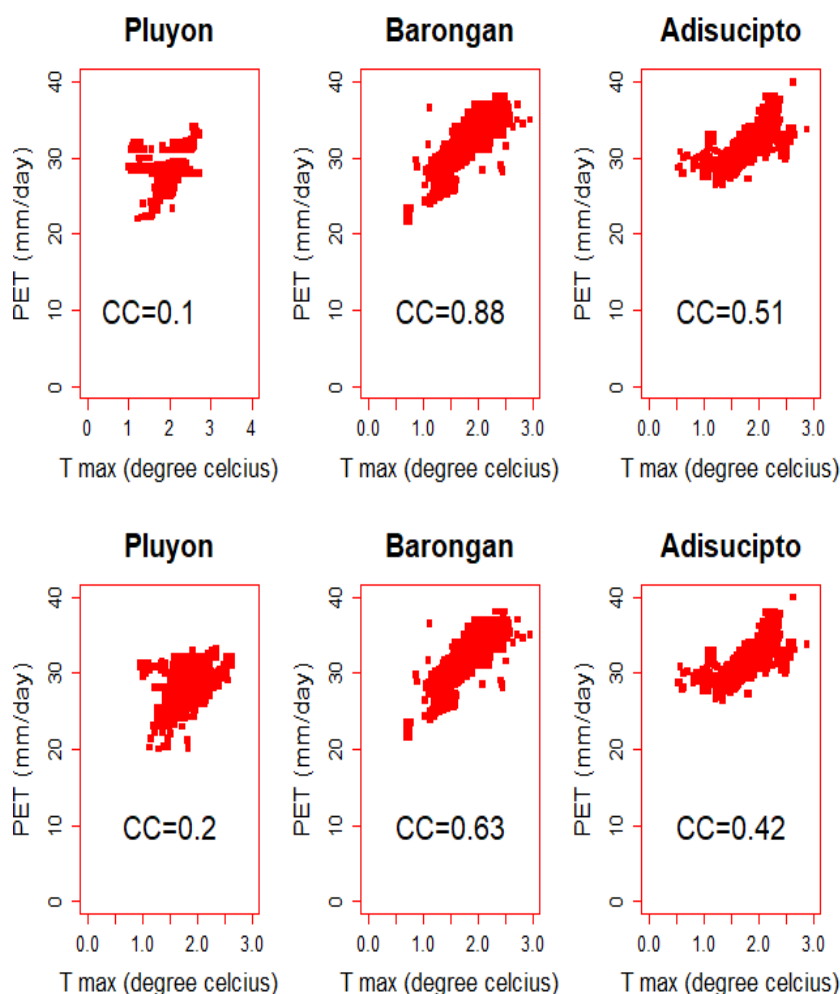


Figure 4. CC of daily PET vs T max (maximum temperature) in three stations in Merapi Aquifer System in wet (above graph) and dry seasons (below graph) separately from 1 January 2005 to 31 December 2016

Barongan station also has highest correlation coefficient between daily maximum temperature with daily potential evapotranspiration in dry season (Figure 4). Barongan station has a coefficient correlation of 0.63, while Adisucipto and Pluyon respectively 0.42 and 0.2. Coefficient correlation between daily maximum temperature and daily potential evapotranspiration is mostly lower in dry season than in rainy season. It seem dry period and higher maximum temperature in dry season do not effect on potential evapotranspiration since coefficient correlation in dry season is low. Global warming up as indication of climate change do not highly impact on potential evapotranspiration. It is probably because a lot of

variable influencing PET such as city water withdrawal and scale of impervious land surface (Koelbing, Schuetz, & Weiler, 2021).

The trends of monthly PET based on the 5-month moving average shows there is no abrupt changes of PET for three stations in Merapi Aquifer System due to changes in climate change (Figure 5). The trend of PET in Pluyon station is mostly stable from January 2005 to December 2016 which is high PET in rainy season and low PET in dry season. Changes of PET trend in Pluyon station significantly shows different behavior from October 2010 to June 2011. There is a drop of PET values during those periods of October 2010 to June 2011. Barongan and Adisucipto stations mostly experiences similar trends in the beginning of year that are the rising of PET values around November 2007. The similar case of drop of PET values also occurs in Barongan station during December 2010 to June 2011. The trend of PET within these months are relatively stable in Adisucipto station.

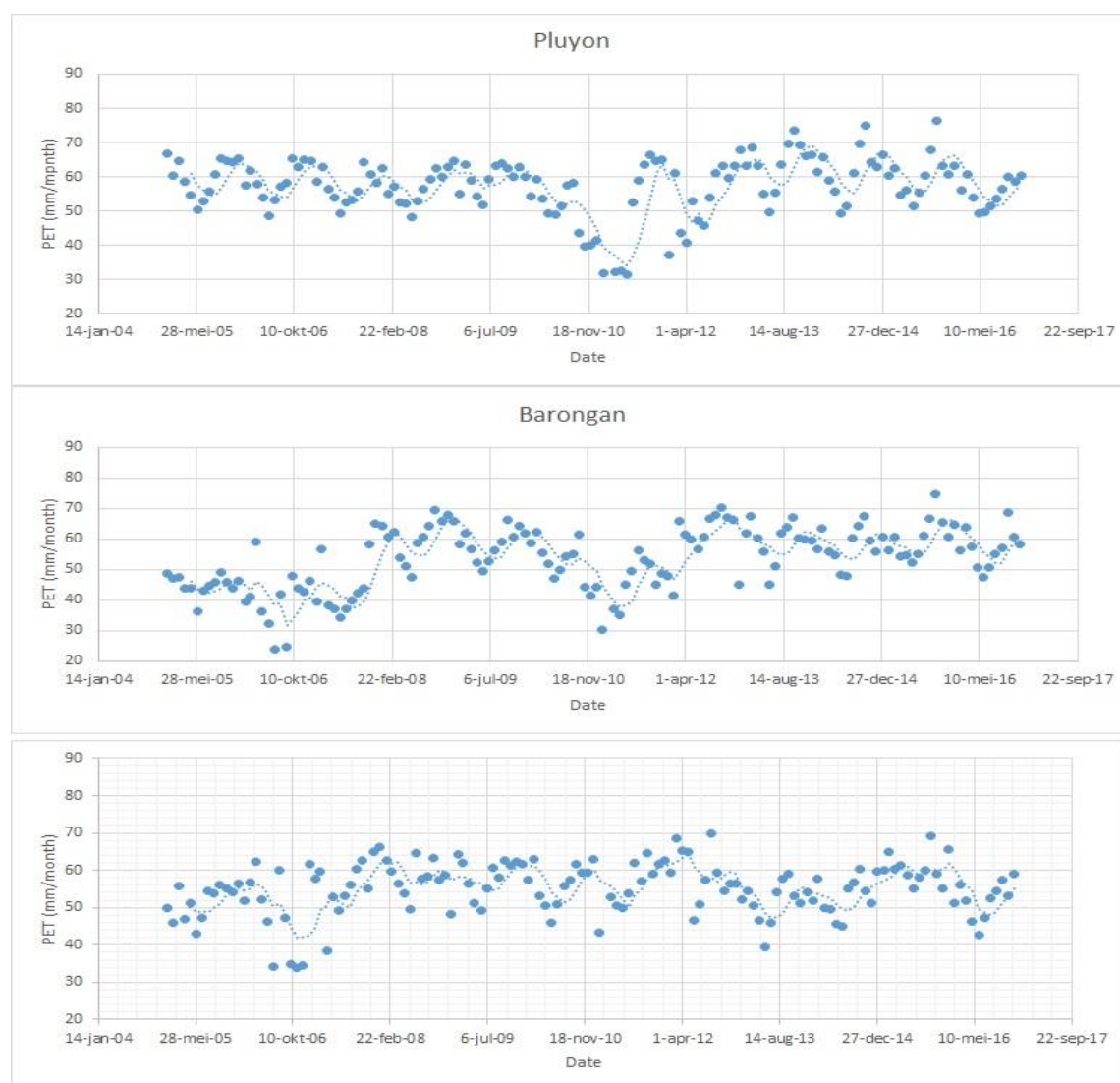


Figure 5. The 5-month moving average trend of monthly PET in Pluyon, Barongan and Adisucipto Stations

Conclusion

The lowest daily PET values is in Adisucipto station where this station is situated in the city center and dense populated areas. The small variation values of PET occurs in all of three stations in Merapi Aquifer System that are in Pluyon, Barongan and Adisucipto stations. The correlation coefficient and PET trends shows there is no significant impact of climate change on PET in Merapi Aquifer. It is probably because local climate mostly influences PET in Merapi Aquifer System compared to global climate such as climate change. It is also possible the impact of climate change can be identified if there is a research with longer datasets.

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