Trend analysis of potential evapotranspiration in peninsular Malaysia

S L S Yong¹, J L Ng¹, Y F Huang², C K Ang³

¹ Department of Civil Engineering, Faculty of Engineering, Technology, and Built Environment, UCSI University Kuala Lumpur, Malaysia
² Department of Civil Engineering, Lee Kong Chian Faculty of Engineering and Science, Universiti Tunku Abdul Rahman Kuala Lumpur, Malaysia
³ Department of Mechanical Engineering, Faculty of Engineering, Technology and Built Environment UCSI University Kuala Lumpur, Malaysia
Corresponding authors: ngjl@ucsiuniversity.edu.my

Abstract. Potential evapotranspiration (PET) plays a prominent part in hydrologic water cycle which is responsible for the water from the Earth’s surface travel back to the atmosphere. Climate change brought contradictory changes in PET which led to the inconsistency of PET trend globally. Hence, the present study carried out the trend of potential evapotranspiration using meteorological data from 7 different meteorological stations located in Peninsular Malaysia. Mann-Kendall and Sen’s slope estimator tests were employed in this article for PET trend analysis. Bayan Lepas experienced significant increasing trend for both FAO 56 -Penman Monteith and Mahringer models during Southwest monsoon. For Mahringer model, significant increasing trends were observed at Ipoh and Pulau Langkawi stations during Northeast and inter monsoon 2, respectively. There were only a few meteorological stations experienced decreasing trend throughout the period. Although the combinations of increasing and decreasing PET trends were observed, it can be highlighted that majority of the PET time series exhibited increasing trend in Peninsular Malaysia.

1. Introduction
Climate change has proved to be a global concern over the years due to its catastrophic impacts. From the agricultural perspective, widespread changes in climate pattern threaten the fresh water supply and increase the risk of floods. Intergovernmental Panel on Climate Change (IPCC) [1] pointed out that the uncommon changes in climate has been observed globally. There is a surge in frequency of warm temperature extremes and heavy precipitation globally [2]. There is a surge in global average temperature across land and ocean surface areas (0.85°C warming) for the period 1880-2012. Consequently, the contradictory changes in potential evapotranspiration (PET) components (aerodynamic, radiative and thermal) has led to the inconsistency of PET trend globally. A better comprehension of PET trend is of paramount importance to the management of water resources in tropical regions which are rich in biodiversity. The study of PET trend could contribute to a better understanding for meteorologists, design engineers and other related professions to develop better project planning in dealing with climate change phenomenon. Any changes in PET could substantially affect biodiversity in tropical forest, particularly Peninsular Malaysia. Approximately 60% of Peninsular Malaysia land is covered by forests [3]. Evapotranspiration (ET) has been acknowledged as
a core process in hydrological cycle. The term ET refers to the combination process of evaporation and transpiration that happen concurrently. [4] expressed the term PET as the water quantity that can potentially evaporate and transpire from vegetation without any constraint. PET can be measured using empirical model which integrated solar radiation, temperature, relative humidity and wind speed.

Trend detections in time series data such as inconsistency and non-homogeneity can be performed through the application of parametric and non-parametric statistical methods. The expected distribution of the data set is the decisive factor when it comes to the selection of statistical method. Parametric methods require data that follow the normal distribution, free from outliers and independent. Non-parametric methods, as opposed to parametric methods require data sets that are independent [5]. A number of PET trend studies had been carried out globally and locally. [6] analyzed PET to detect the trends in Karnal district of Haryana, India. Statistically significant decreasing trends of PET were observed over the period of 1981-2011. In Malaysia, [7] conducted the trend analysis for rainfall, PET and rainfall deficit at Alor Setar station. Although there was no statistically significant trend detected for PET, an increasing PET was observed from June to November at 5% significant level. This indicated that the high ET rate in these months led to the occurrence of rainfall deficit. [8] carried out a study on trend analysis of PET and climatic water balance for the entire Peninsular Malaysia. The results demonstrated that an increasing trend of PET at majority of the stations especially during Southwest monsoon. This is due to the rising monthly temperature and drier climate condition experienced during Southwest monsoon. In contrast, a downward trend of climatic water balance was revealed. This could lead to water deficiency which triggers the drought episodes especially for the central regions (i.e. Selangor and Negeri Sembilan) and the regions that have never encountered drought event. [9] studied the trend analysis of PET and its driving factor for the change in PET in Peninsular Malaysia. The authors claimed that there was a surge in annual and seasonal PET trend. Among all the meteorological parameters, minimum temperature was found increasing rapidly which contribute to the increase in PET. This could affect the atmospheric water balance in Peninsular Malaysia.

Accordingly, the study goal is to determine the trend of potential evapotranspiration on seasonal scale in Peninsular Malaysia. The historical meteorological data of 7 stations for the period of 2009 to 2018 were acquired. Two empirical PET models, namely FAO-56 Penman Monteith and Mahringer models were selected to estimate the PET.

2. Materials and methods

2.1 Study Area
Peninsular Malaysia is situated in Southeast Asia (latitude 1° N to 7° N and longitude 100° E to 104° E) and it covers a total area of 130,590 km2. Peninsular Malaysia experiences two tropical weather phenomenon, which is Northeast monsoon (November-February) and Southwest monsoon (May-August). In between March-April and September-October, two inter-monsoon seasons happen. During the Northeast monsoon period, major rainy season will be taken place especially on the east side of Peninsular Malaysia (e.g. Kelantan) and western part of Sarawak will be exposed to large amount of daily rainfall during the Northeast monsoon. Drier and warmer climate condition will be experienced during the Southwest monsoon [10,11,12]. Peninsular Malaysia receives sufficient solar radiation, which is about 12 hours of daylight hours throughout the year. Malaysia is exposed to rainy, hot and humid in the course of the year with 23-32°C of average temperature and and 2.5-5 mm/day of relative humidity. Generally, the wind speed in Peninsular Malaysia varies between 0.9 and 2.3 m/s [3]. The selected meteorological stations are shown in Table 1. For this study, data set of 10 years consisting of 7 meteorological stations were collected from Malaysia Meteorological Department (MMD) to estimate the PET time series. Four different meteorological parameters, namely the relative humidity (%), wind speed (m/s), solar radiation (MJ/m2), air temperature (°C) were used to compute PET.
Table 1. List of meteorological stations.

| Station Name     | Record Period | Latitude   | Longitude  |
|------------------|---------------|------------|------------|
| Bayan Lepas      | 2009-2018     | 05° 18' N  | 100° 16' E |
| Ipoh             | 2009-2018     | 04° 34' N  | 101° 06' E |
| Kota Bahru       | 2009-2018     | 06° 10' N  | 102° 18'   |
| Kuantan          | 2009-2018     | 03° 46' N  | 103° 13' E |
| Muadzam Shah     | 2009-2018     | 03° 03' N  | 103° 05' E |
| Pulau Langkawi   | 2009-2018     | 06° 20' N  | 99° 44' E  |
| Subang           | 2009-2018     | 03° 08' N  | 101° 33' E |

2.2 Calculation of potential evapotranspiration (PET)

In this study, two empirical PET models were chosen in accordance with input data. The empirical models were categorized into two different groups, namely combination based and mass-transfer based. Combination-based models are the models that involve both aerodynamic theory and energy balance. Mass-transfer based models utilize the concept of eddy motion transfer of water vapor from an evaporating surface to the atmosphere. Table 2 lists the equation for the empirical models. The globally accepted PET model, FAO 56-PM model which recommended by the Food and Agricultural Organization in 1988 was selected in this study [13]. The input parameters were comprised of minimum and maximum temperature, sunshine hours, wind speed, and relative humidity. FAO 56-PM model has proved to have outstanding performance in estimating PET under different climate conditions owning to the consideration of both meteorological and physiological crop variables in PET estimation. Mahringer model is one of the mass-transfer based models that is fundamentally based on Dalton’s gas law. Unlike FAO 56-PM model, Mahringer model requires less input parameters such as wind speed, relative humidity and temperature.

Table 2. Methods for potential evapotranspiration (PET) estimation.

| Classification     | Method (abbreviated) | Equation |
|--------------------|-----------------------|----------|
| Combination        | FAO 56-PM [13]        | \[PET = \frac{0.408\Delta(R_n - G) + \gamma }{\Delta + \gamma (1 + 0.34 u_2) \left( \frac{900}{T_{mean}} + 273 \right) u_2} (e_s - e_a), \] (1) |
| Mass-transfer      | Mahringer [14]        | \[PET = 2.86u^{0.5}(e_s - e_a), \] (2) |

Note: $R_n$ indicates the net radiation of the crop surface (MJm^{-2}day^{-1}); $\Delta$ represents the slope vapor curve (kPa°C^{-1}); $T_{mean}$ represents the daily mean air temperature at 2 m height (°C); $u_2$ represents the wind speed at 2m height (m/s); $G$ represents the soil heat flux density (MJm^{-2}day^{-1}); $e_s$ represents the actual vapor pressure (kPa); $c_i$ is the saturation vapor (kPa); $\gamma$ is the psychrometric constant (kPa°C^{-1}); $u$ is the wind speed (m/s).
2.3 Mann-Kendall (M-K) test
To explore the trend analysis of PET time series, Mann-Kendall (M-K) test is employed to acquire the significance of the PET change. [15]. World Meteorological Organization (WHO) has suggested M-K test to determine the trend in hydrology time series owning to its simplicity and wide application [16]. The Mann-Kendall statistic $S$ is expressed as below:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k)$$  \hspace{1cm} (3)

where $n$ is the length of the time series; $x_j$ and $x_k$ are the PET values at years $j$ and $k$, given that $j>k$, accordingly and $sgn$ represents signum function where

$$sgn(x_j - x_k) = \begin{cases} 
1 & \text{if } x_j - x_k > 0 \\
0 & \text{if } x_j - x_k = 0 \\
-1 & \text{if } x_j - x_k < 0 
\end{cases}$$  \hspace{1cm} (4)

The variance of PET data statistic is expressed as:

$$VAR(S) = \frac{1}{18} n(n - 1)(2n + 5) - \sum_{p=1}^{q} t_p (t_p - 1)(2t_p + 5)$$  \hspace{1cm} (5)

where, $t_i$ represents the number of ties up to PET data sample $i$. The $Z_c$ test statistics is expressed as:

$$z = \begin{cases} 
\frac{S - 1}{\sqrt{VAR(S)}} & \text{if } S > 0 \\
0 & \text{if } S = 0 \\
\frac{S + 1}{\sqrt{VAR(S)}} & \text{if } S < 0 
\end{cases}$$  \hspace{1cm} (6)

2.4 Sen’s slope estimator test
Sen’s slope estimator test provides an indication to deduce the PET trend’s magnitude [17]. It estimates the rate of change per unit time within the PET time series. The slope can be calculated as:

$$Q_i = \frac{x_j - x_k}{j - k}$$  \hspace{1cm} (7)

where $j>k$. The median of Sen’s slope is expressed as follow:

$$Q = Q_{\{N+1/2\}}, \text{if } N \text{ is odd}$$  \hspace{1cm} (8)

or

$$Q = \frac{1}{2} (Q_{\lfloor N/2 \rfloor} + Q_{\{N+1/2\}}), \text{if } N \text{ is even.}$$  \hspace{1cm} (9)
3. Result & Discussion

Table 3 and 4 demonstrated the overall results of M-K and Sen’s slope estimator tests for PET computed using both FAO 56-PM and MA models. The Z values that were positive depicted an increasing PET trend for the period 2009-2018. As can be seen from Table 3 and 4, majority of all seasonal PET values exhibited positive Z value which indicated increasing trend. If the p value is less than 0.05, the trend is significant. Bayan Lepas experienced significant increasing trend for both FAO 56-PM and MA models during Southwest monsoon. For MA model, significant increasing trends were observed at Ipoh and Pulau Langkawi stations during Northeast and inter monsoon 2. These trends are consistent with the Sen’s slope values which showed reasonably higher rate of change in comparison with other meteorological stations. Bayan Lepas station exhibited highest value of Sen’s slope value which were 4.575 and 9.757 at Southwest monsoon for both FAO 56-PM and MA models.

Table 3. Summary of MK test and Sen’s estimator for PET calculated by FAO-56 PM model.

| Station      | Northeast Monsoon series | Inter Monsoon 1 series | Inter Monsoon 2 series | Southwest Monsoon series |
|--------------|--------------------------|------------------------|------------------------|--------------------------|
|              | p-value | Z   | Sen’s slope | p-value | Z   | Sen’s slope | p-value | Z   | Sen’s slope | p-value | Z   | Sen’s slope |
| Bayan Lepas  | 0.727   | 0.111 | 0.955       | 1.000   | 0.022 | 0.151       |          |      |              |          |      |              |
| Ipoh         | 0.601   | 0.156 | 1.857       | 0.862   | -0.067 | -0.595      |          |      |              |          |      |              |
| Kota Bahru   | 1.000   | 0.022 | 1.357       | 0.862   | 0.067  | 0.42        |          |      |              |          |      |              |
| Kuantan      | 0.862   | -0.067 | -0.394     | 0.484   | -0.200 | -0.851      |          |      |              |          |      |              |
| Muadzam Shah | 0.601   | 0.156 | 0.572       | 1.000   | 0.022  | 0.050       |          |      |              |          |      |              |
| Pulau Langkawi | 0.484 | 0.200 | 5.730       | 0.727   | 0.111  | 0.407       |          |      |              |          |      |              |
| Subang       | 0.073   | 0.467 | 3.715       | 1.000   | 0.022  | 0.070       |          |      |              |          |      |              |
|              |          |      |              |          |      |              |          |      |              |          |      |              |
| Bayan Lepas  | 0.727   | 0.111 | 1.959       | 0.041*  | 0.289* | 4.575*      |          |      |              |          |      |              |
| Ipoh         | 0.601   | 0.156 | 1.744       | 0.156   | 0.378  | 2.463       |          |      |              |          |      |              |
| Kota Bahru   | 0.108   | 0.422 | 3.866       | 1.000   | 0.022  | 0.171       |          |      |              |          |      |              |
| Kuantan      | 0.601   | 0.156 | 1.225       | 0.484   | 0.200  | 1.242       |          |      |              |          |      |              |
| Muadzam Shah | 0.108   | 0.422 | 1.610       | 0.727   | 0.111  | 0.369       |          |      |              |          |      |              |
| Pulau Langkawi | 0.108 | 0.422 | 5.219       | 0.727   | 0.111  | 0.707       |          |      |              |          |      |              |
| Subang       | 1.000   | 0.022 | 0.043       | 0.601   | 0.156  | 0.879       |          |      |              |          |      |              |

* Bolded value indicates significant increasing of PET.
Table 4. Summary of MK test and Sen’s estimator for PET calculated by MA model.

| Station          | Northeast Monsoon series | Inter Monsoon 1 series | Inter Monsoon 2 series | Southwest Monsoon series |
|------------------|--------------------------|------------------------|------------------------|--------------------------|
|                  | p-value | Z     | Sen’s slope | p-value | Z     | Sen’s slope | p-value | Z     | Sen’s slope |
| Bayan Lepas      | 0.484   | 0.200 | 5.682       | 0.216   | 0.333 | 2.325       | 0.016    | 0.644 | 9.757       |
| Ipoh             | 0.029\(^{a}\) | 0.556\(^{a}\) | 7.97\(^{a}\)   | 0.484   | 0.200 | 1.713       | 0.156    | 0.378 | 6.434       |
| Kota Bahru       | 0.381   | -0.244 | -2.614      | 0.381   | 0.244 | 1.892       | 0.156    | 0.378 | 5.564       |
| Kuantan          | 0.727   | -0.111 | -2.507      | 0.601   | -0.156 | -1.190      | 0.727    | 0.022 | 1.000       |
| Muadzam Shah     | 0.216   | -0.333 | -2.956      | 0.381   | -0.244 | -1.152      | 0.601    | 0.156 | 1.452       |
| Pulau Langkawi   | 0.291   | 0.289  | 6.219       | 0.381   | 0.244 | 1.495       | 0.291    | 0.289 | 6.219       |
| Subang           | 0.047   | 0.511  | 9.006       | 0.727   | -0.111 | -1.172      | 0.047    | 0.511 | 9.006       |
|                  |          |        |             |          |        |             |          |        |             |
| Bayan Lepas      | 0.716   | 0.378  | 5.682       | 0.216   | 0.333 | 2.325       | 0.016    | 0.644 | 9.757       |
| Ipoh             | 0.029\(^{a}\) | 0.556\(^{a}\) | 7.97\(^{a}\)   | 0.484   | 0.200 | 1.713       | 0.156    | 0.378 | 6.434       |
| Kota Bahru       | 0.381   | -0.244 | -2.614      | 0.381   | 0.244 | 1.892       | 0.156    | 0.378 | 5.564       |
| Kuantan          | 0.727   | -0.111 | -2.507      | 0.601   | -0.156 | -1.190      | 0.727    | 0.022 | 1.000       |
| Muadzam Shah     | 0.216   | -0.333 | -2.956      | 0.381   | -0.244 | -1.152      | 0.601    | 0.156 | 1.452       |
| Pulau Langkawi   | 0.291   | 0.289  | 6.219       | 0.381   | 0.244 | 1.495       | 0.291    | 0.289 | 6.219       |
| Subang           | 0.047   | 0.511  | 9.006       | 0.727   | -0.111 | -1.172      | 0.047    | 0.511 | 9.006       |

\(^{a}\) Bolded value indicates significant increasing of PET.

On the other hand, negative Z value represents decreasing trend in PET time series. Kuantan station experienced decreasing PET trend (Z values of -0.067 and -0.20 for FAO 56-PM model, -0.111 and -0.156 for MA model) for Northeast monsoon and inter monsoon 1. It can be highlighted that decreasing trends were insignificant for all meteorological stations. Although the combinations of increasing and decreasing PET trends were observed, increasing PET trends were being dominant and it can be concluded that majority of PET time series exhibited increasing trend in Peninsular Malaysia.

The graphical representation of the Sen’s linear estimates for the PET time series are shown in Fig. 1. Sen’s slope test with positive value depicts increasing PET trend while the negative value depicts decreasing PET trend. From Figure 1, Kuantan experienced decreasing trend during Northeast monsoon and inter monsoon 1 and positive trend during Southwest monsoon and inter monsoon 2.
As mentioned previously, significant increasing trends were experienced for both PET models during Southwest monsoon. This is due to the rising temperature during Southwest Monsoon. Malaysian Meteorological Department (MMD) stated that the rising in temperature was by virtue of Southwest Monsoon which hot and drier climate will be experienced. [18]. The results are consistent with findings of [7] who discovered increasing PET trend from June to September (Southwest monsoon) in Alor Setar. Furthermore, the results are consistent with the study conducted by [8] where majority of the Peninsular Malaysia regions showed more significant increasing PET trend than climatic water balance (CWB). This might cause water deficiency which consequently contribute to the occurrence of drought events for Peninsular Malaysia.

4. Conclusion

In short, the detection of PET trend has been successfully performed in Peninsular Malaysia. Mann-Kendall test was utilized to access the PET trend at seasonal scale for the period of 2009-2018. Sen’s slope estimator test was utilized to discover the PET trend’s magnitude. The results will convey relevant information for the management of water resources in tropical region, particularly in Peninsular Malaysia. Results indicated that majority of the stations experienced increasing trends throughout the period. FAO-56 Penman Monteith and Mahringer models demonstrated significant increasing trends especially during Southwest monsoon. This is due to the surge in temperature which contributes to the increasing PET trend. Moreover, there was no significant decreasing PET trend for the entire period. The number of stations with decreasing trend are far less than those with increasing trend. Kuantan station experienced decreasing PET trend during Northeast monsoon and Inter monsoon 1.
This study provides an overview of trends in PET in Peninsular Malaysia. Further studies should be carried out by including more regions especially the eastern part of Malaysia in order to provide more valuable information. Also, more trend analysis methods such as Spearman’s Rho test should be included for better comparison.

5. References

[1] IPCC, Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change [Core Writing Team, Pachauri RK, Meyer LA (eds)] IPCC, Geneva, Switzerland 151

[2] Ng J L, Abd Aziz S, Huang Y F, Wayayok A, and Rowshon M K 2016 Analysis of annual maximum rainfall in Kelantan, Malaysia In III International Conference on Agricultural and Food Engineering 1152 pp 11-18

[3] Muhammad M K I, Nashwan M S, Shahid S, Ismail T B, Song Y H and Chung E S 2019 Evaluation of empirical reference evapotranspiration models using compromise programming: a case study of Peninsular Malaysia Sustainability 11 pp 4267

[4] Lu J, Sun G, McNulty S G, and Amatya D M 2005 A Comparison of Six Potential Evapotranspiration Methods for Regional Use in the Southeastern United States J. Am. Water Resour. Assoc. 41 pp 621-633

[5] Jha M K, and Singh A K 2013 Trend analysis of extreme runoff events in major river basins of Peninsular Malaysia Int J Water 7 pp 142-158

[6] Patle G T, Singh D K, Sarangi A, Rai A, Khanna M, and Sahoo R N 2013 Temporal variability of climatic parameters and potential evapotranspiration Indian J. Agric. Sci. 83 pp. 518-524

[7] Ahmad A A, Yusof F, Mispan M R, and Kamaruddin H 2017 Rainfall, evapotranspiration and rainfall deficit trend in Alor Setar, Malaysia. Mal. J. of Fund. Appl. Sci. 13 pp 400-404

[8] Hui-Mean F, Yusop Z, and Yusof F 2018 Drought analysis and water resource availability using standardised precipitation evapotranspiration index Atmos. Res. 201 pp 102-115

[9] Pour S H, Abd Wahab A K, Shahid S, and Ismail Z B 2020 Changes in reference evapotranspiration and its driving factors in peninsular Malaysia. Atmos. Res. 105096

[10] Lin N J, Abd Aziz S, Feng H Y, Wayayok A, and Kamal M R 2015 Homogeneity analysis of rainfall in Kelantan, Malaysia J. Teknol. 76

[11] Ng J L, Abd Aziz S, Huang Y F, Mirzaei M, Wayayok A, and Rowshon M K 2019 Uncertainty analysis of rainfall depth duration frequency curves using the bootstrap resampling technique. J. Earth Syst. Sci. 128 113

[12] Ng J L, S. Y. Yap S Y, Huang Y F, Noh N M, Al-Mansob R A, and Razman R 2020 Investigation of the best fit probability distribution for annual maximum rainfall in Kelantan River Basin. IOP Conf. Ser: Earth Environ. Sci. 47 p 012118

[13] Allen R G, Pereira L S, Raes D, and Smith M 1998 Crop evapotranspiration: Guidelines for computing crop water requirements. Irrigation and Drainage Paper No 56. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

[14] Mahringer W 1970 Verdunstungs Studien am Neusiedler See Theor. Appl. Climatol. 18 pp. 1–20

[15] Kendall M G 1975 Rank correlation methods 4th edition Charles Griffin& Co. Ltd, London

[16] Tian Q, Wang Q, Zhan C, Li X, and Liu X 2012 Analysis of climate change in the coastal zone of eastern China, against the background of global climate change over the last fifty years: case study of Shandong peninsula, China Int J. Geosci. 3 pp 379

[17] Sen P K 1968 Estimates of the regression coefficient based on Kendall’s tau J. Am. Stat. Assoc. 63 pp 1379–1389

[18] Hamzah F M, Saimi F M, and Jaafar O 2017 Identifying the Monotonic Trend in Climate Change Parameter in Kluang and Senai, Johor, Malaysia Sains Malays. 46 1735-1741
Acknowledgement
The authors are grateful to the Malaysian Meteorological Department (MMD) for the provision of meteorological data. The authors would like to acknowledge the sincere appreciation towards the financial support from the UCSI University through Pioneer Scientist Incentive Fund (PSIF) under project code Proj-2019-In-FETBE-065.