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REFERENCE EVAPOTRANSPIRATION (ET_O) IN TROPICAL FORESTED AREAS DETERMINED BY PENMAN-MONTEITH MODEL IN CROPWAT SOFTWARE

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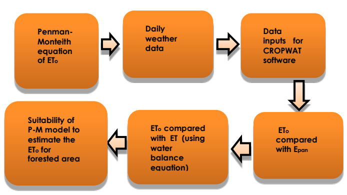
Graphical abstract



Abstract

Reference evapotranspiration (ET_o) was determined using the Penman-Monteith (P-M) combination equation established in the CROPWAT software v.8 (FAO 1992). The objective of the study is to determine the ET_o at Bukit Tarek Experimental Watershed, Kerling, Selangor (BTEW), Matang Mangrove at Kuala Sepetang, Perak (MMP) and FRIM Mata Ayer Research Station, Perlis (MAP) using five-year periods of daily weather secondary data. Results showed that ET_o of 4.10 mm/day at MMP was the highest compared to MAP (3.70 mm/day) and BTEW (3.58 mm/day). The geographical latitude influenced the ET_o values. The ET_o at BTEW was compared with the evapotranspiration (ET) calculated from water balance method which is also at the same location for data period from 1990 to 1994. Results showed that annual average ET was 1552 mm (56.1% of rainfall) while ET_o was 43.9% of rainfall only. The annual averages of ET ranged from 3.92 to 4.69 mm day^{-1} with an average of 4.27 mm day^{-1}. The annual average of ET_o was underestimated ET from water balance method ranging from 16.6 to 26.2%. It is expected that the ET_o found was underestimated as the actual evapotranspiration requires changes in canopy resistance as function of water availability.

Keywords: Tropical lowland forest; evapotranspiration; water balance; Penman-Monteith model

Abstrak

Evapotranspirasi rujukan (ET_o) ditentukan dengan gabungan formula Penman-Monteith (P-M) yang dibangunkan di dalam perisian CROPWAT v.8 (FAO 1992). Tujuan kajian ialah menentukan nilai ET_o di kajian tadahan Bukit Tarek, Kerling, Selangor (BTEW), Matang bakau di Kuala Sepetang, Perak (MMP) dan Stesen Penyelidikan FRIM, Mata Ayer, Perlis (MAP) dengan menggunakan data cuaca sekunder untuk jangkamasa 5 tahun. Keputusan menunjukkan ET_o sebanyak 4.10 mm/hari di MMP adalah paling tinggi dibandingkan di MAP (3.70 mm/hari) dan BTEW (3.58 mm/hari). Kajian ini menunjukkan nilai ET_o adalah dipengaruhi oleh latitude geografi. ET_o di BTEW dibandingkan dengan nilai evapotranspirasi (ET) yang dikira dengan menggunakan kaedah inbangan air pada lokasi yang sama bagi jangkamasa data dari 1990 hingga1994. Keputusan menunjukkan nilai purata tahunan ET adalah sebanyak 1552 mm iaitu bersamaan 56.1% (jumlah hujan tahunan) manakala ET_o sebanyak 43.9% dari jumlah hujan sahaja. Nilai purata tahunan ET antara 3.92 sehingga 4.69 mm/hari dengan nilai purata 4.27 mm/hari. Nilai purata tahunan ET_o adalah di bawah paras nilai ET dari kaedah imbangan air iaitu antara 16.6 hingga 26.2 %. Adalah dijangkakan nilai ET_o lebih rendah memandangkan nilai evapotranspirasi sebenar perlu menunjukan perubahan dalam rintangan kanopi terhadap fungsi kehadiran air.

Kata kunci: Hutan tanah darat; evapotranspirasi; imbangan air; model Penman-Monteith

1.0 INTRODUCTION

Evapotranspiration (ET) is part of the component in the hydrological cycle and the basic that need to be understand in the management of water resources. The quantity of water that consumed by the vegetation influence the volume of water that reaches the river systems and the amount of water resources that is available to the other consumers in the ecosystem and at the downstream areas. The value of ET varies spatially with differences in the vegetation type and density on land surfaces. The changes in weather and climate daily or seasonally also affect ET temporarily.

Monitoring ET for forest environment is already known required great challenge as it needs specific and costly equipment. There are many methods available to measure ET depending on location and land surface. Water balance equation has been identified suitable to be applied in a forested catchment. In this method, the measurement of discharge using paired catchment method requires weir construction at the river outlet and it is costly and difficult to construct weir structures located in the remote forest area with hard accessibility.

As an alternative, semi empirical equation such as Penman-Monteith equation has been used to estimate potential evapotranspiration based on surface weather observation. Climate station is also established for reference of weather condition at the study site when initiating hydrological research. The climatic data can be used to calculate the reference evapotanspiration (ET_o) using Penman-Monteith model (Allen *et al.*)[1]. The parameters needed are air temperature, relative humidity, windspeed, and daily sunshine duration or solar radiation.

The earliest water balance study was carried out by Low and Goh [2] for five catchments in Selangor, Malaysia. The annual water loss from the water balance ranges from 993 to 1263 mm (Rainfall, P = 2163 mm) depending on the characteristics of each catchment. Their studies indicated that annual potential evaporations were higher than the actual evaporations but were not much different among the catchments which converged around 1200 mm yr^{-1}. The similar method used by Shuttleworth [3] showed that the annual ET from mature lowland rainforest at Manaus, Brazil was 1315 $mmyr^{-1}$ (P = 2720 mm). Studies at Lambir Hills National Parks in Sarawak by Kumagai *et al.* [4] using eddy-covariance method and Manfroi *et al.* [5] using energy balance method found that the annual ET values were quite high with 1545 $mmyr^{-1}$ (P= 2740 mm) and 1639 $mmyr^{-1}$ (P=2150 mm), respectively.

The objective of this paper is to determine the reference evapotranspiration (ET_o) for three forest areas located in the lowland tropical forest. The Penman-Monteith model which used the surface energy and aerodynamic processes applied in the CROPWAT software was used to calculate the ET_o values.

The value of soil flux density (G) at less than 1 meter below the surface is considered very small and as such

1.1 Weather Station Locations

The secondary climatic data observed at Bukit Tarek Experimental Watershed (BTEW), Kerling, Selangor from 1990–1994, Matang Mangrove, Perak (MMP) from 1990–1994 and Mata Ayer, Perlis (MAP) from 1993–1997 were used in the data analysis. The daily climatic parameters observed from the three locations were maximum and minimum air temperatures (°C), relative humidity (%), sunshine duration (hr), wind speed (km/day) and rainfall (mm). The monthly averages from the five years of data observation were used in the calculation of ET_o.

Bukit Tarek Experimental Watershed (BTEW) is located in Compartment 41, Bukit Tarek Tambahan forest reserve, Kerling, Selangor (lat 3°31’ N and long 101°35’ E), about 80 km to the north of Kuala Lumpur. The climate station of Matang Mangrove is located at Kuala Sepetang, Taiping in Perak state (lat 40° 50’N and Long 100° 38’E), near to the seaside. The FRIM’s Mata Ayer Research Station is at located in Compt. 23, Mata Ayer Forest Reserve, Perlis (6° 5’N and 100° 14’E), near to the border of Thai.

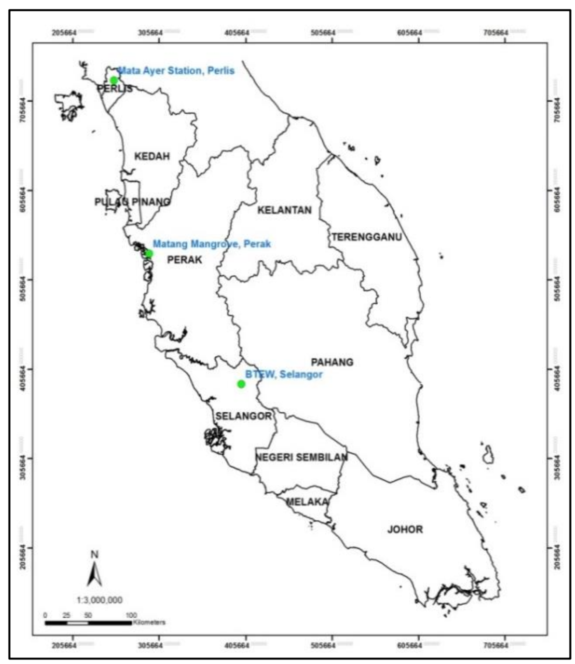


Figure 1 Weather station established at the three locations which data were used in calculation of ET_o

2.0 METHODOLOGY

ET_o is the evapotranspiration rate from a reference surface, not short of water. The reference surface is a hypothetical grass surface with specific characteristics. As the factors affecting the ET_o are climatic parameters, the ET_o expresses the evaporating power of the atmosphere at a specific location and time of the year.

G is nil in the P-M equation. As the ET_o is only as reference to short grass surface, crop coefficient, k is necessary for calculation of actual ET.

The P-M equation (Monteith [6]; Monteith and Unsworth [7] has been recommended by FAO as the most appropriate method to determine crop water requirement. CROPWAT is a decision support system developed by the Land and Water Development Division of FAO for planning and management of irrigation. The ET_o is calculated using the FAO 1992 [8] Penman-Monteith method in the CROPWAT 8.0 version. The P-M model is recommended as the sole method for determining ET_o as it closely approximates grass ET_o and explicitly incorporates both physiological and aerodynamic parameters. The use of ET_o and crops coefficient (k_c) values can be used to estimate the ET of crops. The daily ET_o determines by the P-M equation (Allen *et al*.[1]; Allen *et al*. [9] as the following:

$$ET_o = \frac{0.408\Delta (R_n - G) + \gamma \left[\frac{900}{T_{mean}+273}\right] u_2 (e_s - e_a)}{\Delta + \gamma (1+0.34u_2)}$$

Where;

ET_o = Reference evapotranspiration (mm/day),
R_n = Net radiation at the crop surface ($MJ/m^2/day$),
G = Soil heat flux density ($MJ/m^2/day$), which can be neglected (G=0),
T_{mean} = Mean air temperature (°C),
u_2 = Wind speed measured at 2 m height (m/s),
e_s = Saturation vapor pressure (kPa),
e_a = Actual vapor pressure (kPa),
$e_s - e_a$ = Saturation vapor pressure deficit (kPa),
Δ = Slope vapor pressure curve (kPa/°C),
γ = Psychrometric constant (kPa/°C).

The data inputs for CROPWAT software are daily solar radiation or sunshine duration, minimum and maximum temperatures, wind speed and relative humidity. These climate data were observed at the standard height of 2-m over land surface at the three locations. The sunshine duration used in the estimation of R_n in this study was measured by the Campbell-Stokes sunshine recorder. The temperatures were determined by dry and wet bulb thermometers, windspeed by wind odometer and E_{pan} by U.S Class-A pan evaporation (E_{pan}). The daily ET_o was automatically calculated in the CROPWAT software after computation of the data.

The daily observation of stream water level, climatic parameters and monthly rainfall from years 1990 to 1994 at Bukit Tarek Experimental Watershed were used in data analysis of water balance equation and compared with P-M equation.

3.0 RESULTS AND DISCUSSION

Generally, small fluctuations of monthly ET_o were shown by the P-M model (Figure 2, 3 & 4) with the monthly average of ET_o observed from as low as 2.61 $mmday^{-1}$ at BTEW, Selangor and MAP,Perlis to as high as 4.90 $mmday^{-1}$ at MMP, Perak. Monthly values of ET_o were higher in months of February, Mar and April and decreased toward the end of the year. Pattern was found similar at the three locations. The maximum ET_o was found in March while the minimum occurred within months of October to November.

With 365 days yearly and values obtained in Table 1, the percentage of rainfall that loss as ET_o were 46.4% (BTEW), 66.8% (MMP) and 74.7% (MAP), which MAP shows high percentage followed by MMP and BTEW. This is might due to the high value of ET_o produced with less volume of rainfall received in MAP, resulted in high percentage compare to other two stations. Each ET_o values does get influence by the distinct different in temperatures of each locations as Matang Mangrove at Kuala Sepetang, Perak located near to the coastal area while Mata Ayer, Perlis is at the northern part of Peninsular Malaysia and Bukit Tarek, Selangor is at the inland area. The different forest cover types at each location also contribute to the variation in ET_o values.

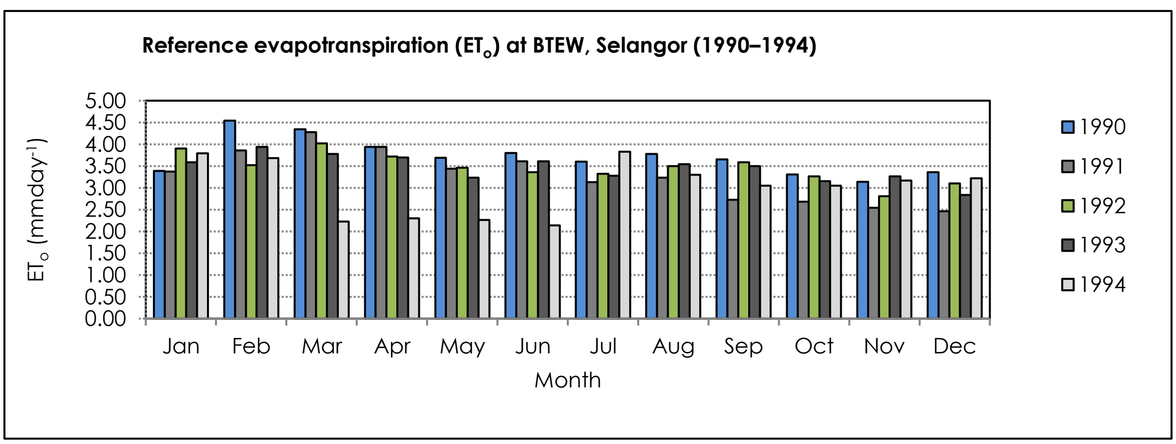


Figure 2 The higher monthly ET_o were gained from February to April except in 1994. In 1994, ET_o values were also quite low compared to other years from May to June. The ET_o ranged from 2.14 to 4.54 $mmday^{-1}$ for 5-year period

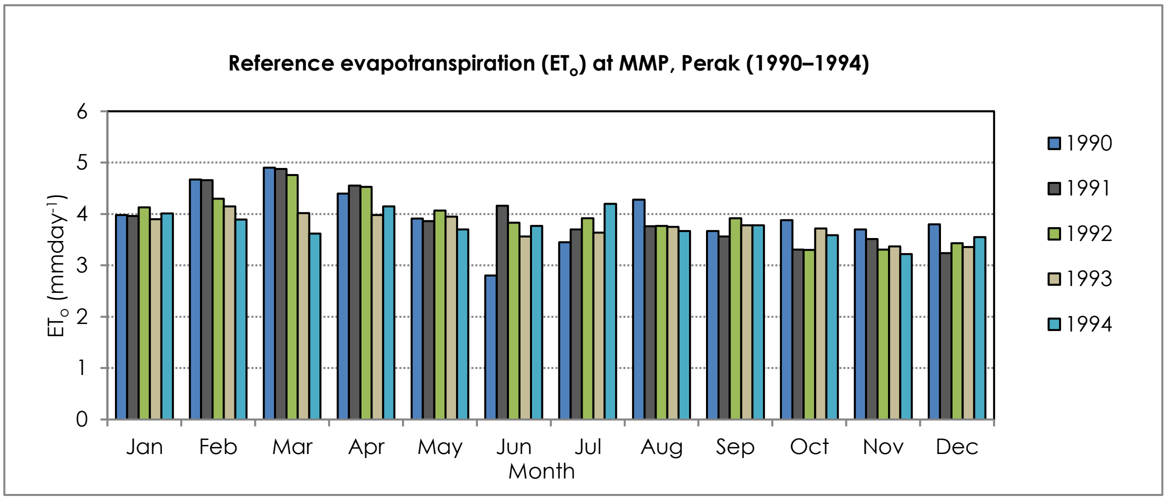


Figure 3 Average monthly of ET_o in a mangrove forest with range of values from 2.80 to 4.90 mmday^{-1}. The average for five years period is 3.87 mmday^{-1}

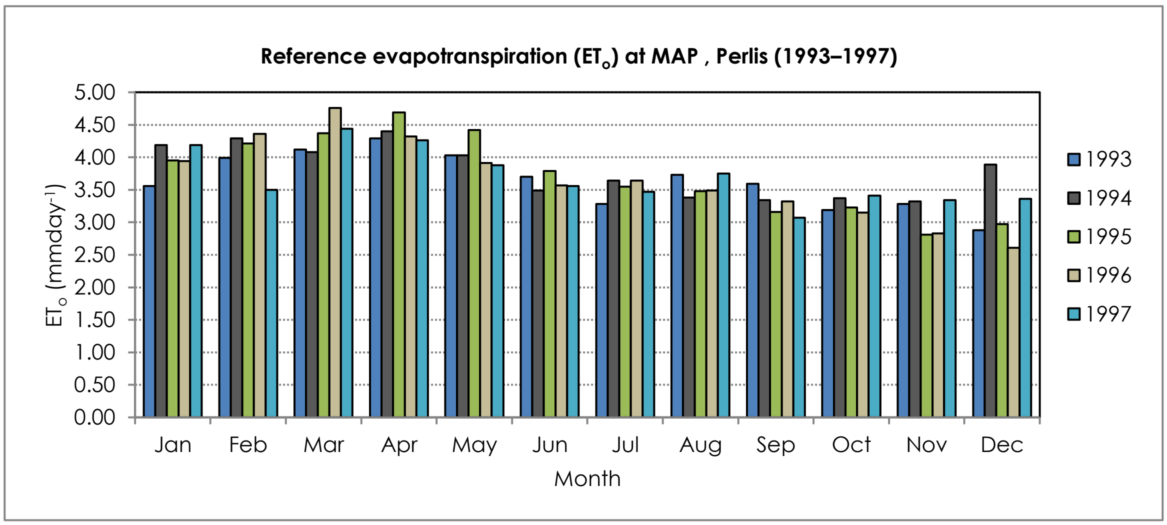


Figure 4 Average monthly of ET_o in a matured forest plantation with range of values from 2.61 – 4.76 mmday^{-1}. The average value for five years periods is 3.70 mmday^{-1}

Table 1 Based on location, the ET_o was lowest in the inland forest of BTEW (3.38 mmday^{-1}), Selangor followed by MAP (3.70 mmday^{-1}), Perlis and MMP, Perak which is located near to the seaside. Note : P = Rainfall

(a) BTEW, Selangor

Year	ET_o	E_{pan}	P
	mm/day	mm/day	mm
1990	3.71	3.9	2348
1991	3.27	3.8	3135
1992	3.46	4.0	2652
1993	3.45	3.6	3189
1994	3.00	3.2	2765
Avg	3.38	3.7	2818

(b) MMP, Perak

Year	ET_o	E_{pan}	P
	mm/day	mm/day	mm
1990	3.95	3.4	2539
1991	3.93	2.9	2587
1992	3.94	2.6	1862
1993	3.76	3.2	1907
1994	3.76	3.4	1794
Avg	3.87	3.1	2138

(c) MAP, Perlis

Year	ET_o	E_{pan}	P
	mm/day	mm/day	mm
1993	3.64	3.7	1621
1994	3.79	3.5	1659
1995	3.72	3.6	1778
1996	3.66	3.7	2188
1997	3.69	3.6	1711
Avg	3.70	3.6	1792

The comparison of ET_o and ET calculated from water balance at BTEW, Selangor was carried out to determine the differences between the two methods. The fluctuation of monthly ET obtained was totally different from the ET_o (Figure 5). In Malaysia, Based on the Review of The National Water Resources Study

2000–2050 (NWRS) conducted in 2011, from the total amount of rainfall received in Peninsular Malaysia, 43% goes to surface runoff, 51% evaporates into the atmosphere, while another 6% becomes ground water recharge. This means that forest release higher amount of water into the atmosphere.

Table 2 shows average of five years rainfall was 2818 mm and 43.9% out of this amount became discharge in the river system while another 56.1% evaporated back into the atmosphere. Dense forest canopy produces high evapotranspiration rate and also control the rainfall-runoff processes on land surface. The ET_o can be as low as 1.00 mmday^{-1} in 1994 and as high as 8.83 mmday^{-1} in 1990 (Table 3). The yearly average ET was 4.27 mmday^{-1} for five years period of observation.

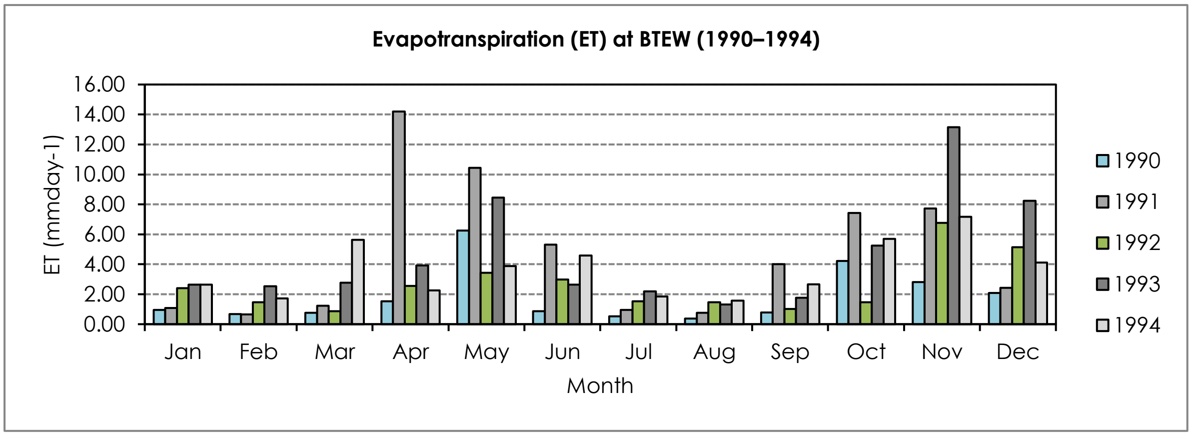


Figure 5 Monthly evapotranspiration were fluctuated in accordance to the daily discharge. Two peaks of ET were indicated in May and November which occurred during monsoon seasons. Lesser ET was determined using water balance equation from January–March and July–September. There is an extreme ET value found in April 1991. The ET ranged from 0.37 to 13.1 mmday^{-1}

Table 2 Annual discharge and evapotranspiration at BTEW calculated from water balance equation

Year	Rainfall (P) (mm)	Discharge (Q) (mm)	Evapotranspiration (ET)/(mm)	ET (% of rainfall)
1990	2348	668.9	1679.1	71.5
1991	3135	1709.4	1425.6	45.5
1992	2652	946.6	1705.4	64.3
1993	3188	1671.1	1516.9	47.6
1994	2765	1334.5	1430.5	51.7
Average	2818	1226.2	1551.5	56.1

Table 3 The range of yearly average of evapotranspiration at BTEW using water balance equation (1990–1994)

	Annual average of evapotranspiration, ET (mmday^{-1})				
	1990	**1991**	**1992**	**1993**	**1994**
Min	2.04	0.74	0.59	1.91	1.00
Max	8.83	7.18	7.83	6.62	8.59
Average	4.60	3.92	4.69	4.16	3.96

Table 4 Monthly average of weather data, rainfall and pan evaporation observed at BTEW and reference evapotranspiration (ET_o) calculated from P-M model in the CROPWAT software (1990 –1994)

Year	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Windspeed ($kmday^{-1}$)	Sunshine (hours)	ET_o ($mmday^{-1}$)	E_{pan} ($mmday^{-1}$)	Total Rainfall (mm)
1990	20.1	34.3	81	26	5.8	3.71	3.87	2348
1991	21.2	33.1	82	21	4.3	3.27	3.77	3135
1992	21.5	33.6	81	19	4.9	3.46	3.96	2652
1993	21.6	33.2	82	13	5	3.45	3.64	3188
1994	22.1	32.6	83	9	3.5	3.00	3.19	2765
Average	21.3	33.4	81.8	17.6	4.7	3.38	3.68	2818

Table 4 shows that characteristics of the climatic parameters at the BTEW were not much different within periods of observation which the highest of maximum temperature was up to 39.1°C in 1990 and the lowest of minimum temperature was as low as 14°C in 1992. The relative humidity ranged from 53.2 to 97.8%, daily sunshine duration can reach up to 12.3 hours and wind speed ranged from 0.09 to 390 $kmday^{-1}$. Evaporation also determined using evaporation pan which the values ranged from 0.07 to10.6 $mmday^{-1}$.

The average ET of 56.1% determined by water balance method was compatible with the previous studies by Low & Goh [2] with 55.1% of rainfall but it was higher compared to Shuttleworth [3] with 48.3% of rainfall. The difference from the two studies could be due to vegetation characteristics and forest density in each catchment.

The comparison of evapotranspiration values obtained from the methods of water balance, P-M model and pan evaporation indicated that the pattern are similar in which values in 1990 were higher than 1991, increased in 1992 and decreased in 1993 and 1994. The ET_o was found lower than the other two methods (Table 5).

Reference evapotranspiration which is referred to the grass water requirement is related to the process with the assumption that it occurs without water stress. Thus, this can be associated with the less fluctuation of the values of ET_o calculated in this study. It is necessary to represent the changes in the canopy resistance to represent water availability in the actual evapotranspiration (Jarvis [10]; Stewart [11]; Silva [12]).

Furthermore, if we want to estimate the potential evapotranspiration, the value of crop coefficient (k_c) is needed which is not available for the tropical forest value due to complexity of the forest in modeling purposes.

Table 5 Comparison of evapotranspiration from water balance method (ET), reference evapotranspiration (ET_o) from P-M model and pan evaporation (E_{pan})

Year	ET ($mmday^{-1}$)	ET_o ($mmday^{-1}$)	E_{pan} ($mmday^{-1}$)	Diff between ET & ET_o (%)
1990	4.60	3.71	3.87	19.3
1991	3.92	3.27	3.77	16.6
1992	4.69	3.46	3.96	26.2
1993	4.16	3.45	3.64	17.1
1994	3.96	3.00	3.19	24.2
Average	4.27	3.38	3.68	20.8

4.0 CONCLUSION

The location with different weather condition and forest cover characteristics determine the value of reference evapotranspiration (ET_o) calculated by the P-M model in the Cropwat software. The study found that the reference evapotranspiration (ET_o) under estimated the ET determined from water balance equation with the different obtained was quite high that is between 17 to 26%. It is suggested that some modification or improvement to the P-M model in order to make it presentable to measure the ET_o for tropical forest.

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