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# ESTIMATION OF EVAPOTRANSPIRATION IN OIL PALM CATCHMENTS BY SHORT-TIME PERIOD WATER-BUDGET METHOD

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**Abstract:** Short Time Period Water Budget (SPWB) and Catchment Water Balance (CWB) methods were used for estimating evapotranspiration (ET) rates in oil palm catchments in Johor, Malaysia. Three catchments of different oil palm ages were established, namely C1 (2 years), C2 (5 years) and C3 (9 years). Eight months data of rainfall and runoff were used in the analysis. By adopting no rainfall conditions (*Pse*=0) at the start and end days of analysis, we obtained water budget periods of 209 days for C1, 111 days for C2, and 158 days for C3. A higher *Pse* of 2 mm, has prolonged the water budget periods to 218, 206 and 195 days for C1, C2 and C3, respectively. The larger *Pse* (2mm) also increased the number of samples for analysis. The SPWB method showed more consistent monthly ET compared to the WBC method. The projected rates of annual *ET* show remarkable variations between catchments, from 927 to 1405 mm/yr for the SPWB method and 1098 to 1365 mm/yr for the CWB method. Although the annual *ET* rates from C1 (1405 mm/yr for SPWB and 1365 mm/yr for CWB) are reasonable, the *ET* values in C2 and C3 seemed to be grossly underestimated. Both methods have weaknesses in dealing with distinct dry and wet conditions, most likely due to rapid fluctuation in the soil moisture. This problem is more obvious in the smallest catchment, C2.

**Keywords:** *Oil Palm Catchment, Evapotranspiration, Short Time Period Water Budget, Catchment Water Balance*

## 1 Introduction

Oil palm (*Elaeis guineensis*) plantation is one of the major landuses in Malaysia. In year 2004, oil palm covers 3.87mil ha, which is about 10% of Malaysia's total land mass. This is a 70-fold increase since 1960's. The annual export of various oil palm produces has risen from RM 19.6 billion in year 2002 to RM 26.15 billion in 2003. In 2004, the export value exceeded RM30 billion (MPOB, 2004). The continual bright prospect of palm oil industry has led to rapid expansion of oil palm plantations including in the neighbouring countries, especially Indonesia. As time passes, most of the suitable agricultural lands have been developed or converted to plantation areas. It is most likely that the future expansion will be on less ideal sites, such as on steep terrain or deep peat soils which are potentially more disruptive to the environment. Depending on the nature and extent of disturbances, these land use activities could pose moderate to permanent and irreversible changes to the hydrological regimes (Bruijnzeel, 1990).

Estimation of evapotranspiration (*ET*) rate is important for reasons such as water balance studies and irrigation practice. Unlike evaporation, *ET* cannot be measured directly for a large area. Therefore, many schemes are presented (Brutsaert, 1982) and among those widely used are Penman (1948) and Priestley and Taylor (1972). Undoubtedly, these methods are reliable and also they resulted in other schemes (Brutsaert and Stricker, 1979; De Bruin and Holtslag, 1982). Nevertheless, a lot of meteorological data and watersheds physical characteristics are needed to accomplish the estimation.

In addition to the methods mentioned above, catchment water balance method has been used to estimate annual *ET* (Low and Goh, 1972; Ledger, 1975; Bruijnzeel, 1988; Lesack, 1993). However, the water balance method entailed a long term and continuous rainfall and streamflow measurements to minimize variation in soil moisture. As an alternative, short-time period water-budget (SPWB) method can be used for estimating *ET* when the rainfall and runoff record is short (Linsley *et al.*, 1958; Hamon, 1961). SPWB method was used to estimate monthly *ET* in several watersheds in Japan (e.g., Takase and Maruyama, 1976; Suzuki, 1980; 1985). Shimizu *et al.* (1994) used the method to evaluate the effects of forest cutting on *ET*. Murakami *et al.* (2000) used SPWB method to analyze variation in *ET* in relation to forest stand ages and climate. SPWB method was also used by Takimoto *et al.* (1994) to compare the *ET* between a reclaimed farmland and a natural forest. Except for Noguchi *et al.* (2004) the SPWB method was mostly tested in the temperate region. None of its application has been attempted in plantation ecosystems.

A number of *ET* studies have been carried out in tropical forests (Kuraji and Paul, 1994; Zulkifli *et. al*., 1998; Noguchi *et al*., 2004). However, reported *ET* study in oil palm plantations is almost non exist except that of Dufrene *et al.* (1992) in South Africa and DID (1989) in Pahang. The DID's study however, was terminated before the plantation has reached maturity thus the finding may not represent *ET* value for matured oil palm which cover much larger area than the young ones. This paper highlights results of applying SPWB method in three oil palm catchments of different stand ages.

## 2 Methods

### *2.1 Site Description*

Three experimental catchments were established in Sedenak Estate in Kulai, Johor which is located in the upstream of Skudai River (Figure 1). The general physiographical conditions of these catchments are listed in Table 1. The oil palm seedlings planted in these catchments belong to PAMOL/FELDA clone. The planting design is an equilateral triangle with 8 m gap. Among the three catchments, C1 is the most recently planted (2 years) and the ground is still almost fully covered by *Legume mucuna.* The cover crop is less dense in C2 (5 years) and almost disappeared in C3 (8 years). This is due to light limitation as the oil palms grow bigger and their canopies getting closer. Another reason for the cover crop disappearance is due to frequent use of harvesting machine which compact the soil surfaces. In C2 and C3, the remaining cover crops are mostly confined along streambank.

### *2.2 Field Measurement*

Rainfall between January and August 2006 was recorded continuously using ONSET RG2-M rain gauges (Figure 2). Water level was measured by an MDS-Dipper pressure sensor over a 120° V-notched weir (Figure 3). Each tip of the rain gauge records 0.2 mm rainfall while the pressure sensor recorded water level automatically at a five-minute interval. One rain gauge in each catchment should be sufficient as the catchments are small (the largest is 17.6 ha) and basically conform to the standards for rain gauge density in the tropics (DID, 2000).

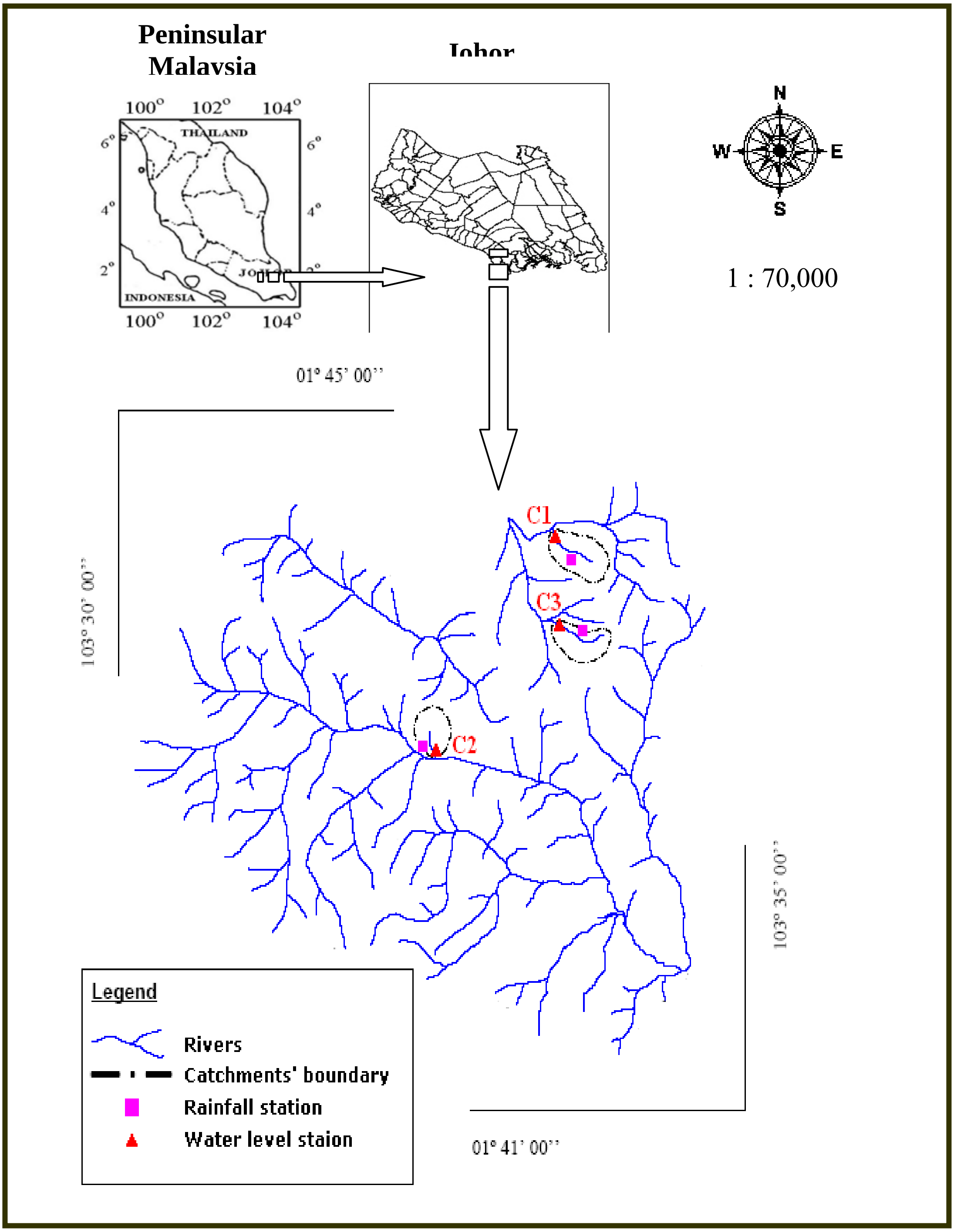


Figure 1: Location of the Sedenak catchment

Table 1: Physiographical characteristics of study catchments

| Catchment | C1 | C2 | C3 |
|---|---|---|---|
| Location | Sedenak Estate, Block P04/A | Sedenak Estate, Block P01 | Sedenak Estate, Block P98 |
| Coordinates | 01° 44' 37" N 103° 32' 41" E | 01° 42' 54" N 103° 31' 47" E | 01° 43' 35" N 103° 32' 42" E |
| Topography | ----------------Undulating-------------- | | |
| Soil texture | Sandy Clay with Organic, red yellow ultisols, Rengam series | | |
| Total area (ha) | 17.59 | 8.17 | 15.62 |
| Stream length (m) | 351 | 153 | 641 |
| Stream max. elevation (masl) | 66.7 | 58.8 | 60.9 |
| Stream min. elevation (masl) | 55.4 | 49.0 | 43.5 |
| Stream slope | 0.0321 | 0.0637 | 0.0271 |
| Stream slope (%) | 9 | 7 | 8 |
| Catchment length (m) | 372 | 221 | 705 |
| Catchment max. elevation (masl) | 67.9 | 63.1 | 62.8 |
| Catchment min. elevation (masl) | 55.4 | 49.0 | 43.5 |
| Mean catchment slope (m/m) | 0.0356 | 0.0916 | 0.0300 |

Figure 2: ONSET RG2-M automatic tipping bucket rain gauge

Figure 3: 120˚ V-notch weir

Discharge rating curves were established for all the three catchments by conducting a series of volumetric gauging during storm events. These rating curves were then used to convert water levels to discharge values. The three rating curves have $R^2$ ranging between 0.86 and 0.98 (Equations 1, 2 and 3), suggesting that the discharge values are strongly correlated with water level.

C1, $Q = 0.0363(H\text{-}46)^{2.3087}$ ($R^2 = 0.98$) (1)
C2, $Q = 0.0037(H\text{-}39)^{2.5668}$ ($R^2 = 0.93$) (2)
C3, $Q = 0.0363(H\text{-}48)^{2.1032}$ ($R^2 = 0.86$) (3)

where $Q$ is discharge (l/s) and $H$ is water level (cm).

### *2.3 Short-time Period Water-budget (SPWB)*

In the SPWB method, the relationship between water storage in a catchment $S(t)$ and the discharge rate $q(t)$ (mm day$^{-1}$) can be written as:

$$S(t) = f\,[q(t), dq/dt] \tag{4}$$

Assuming that $S(t_1)$ is equal to $S(t_2)$ when times $t_1$ and $t_2$ have equivalent values of $q(t)$ and $dq/dt$, the change of water storage ($\Delta S$ ) in the catchment should be negligible or $\Delta S = S(t_2) - S(t_1)$ is equal or close to zero. As such $ET$ for the time period from $t_1$ to $t_2$ can be calculated using equation (5):

$$ET = P - Q = \int_{t1}^{t2} p(t)\,\mathrm{dt} - \int_{t1}^{t2} q(t)\,\mathrm{dt} \tag{5}$$

where $P$ and $Q$ are total precipitation and total discharge at the time period, $t_1$ to $t_2$; $p(t)$ and $q(t)$ are rainfall intensity and discharge rates, respectively.

The following three conditions were applied to determine sets of the beginning and the end times of the analysis periods, $t_1$ and $t_2$ (Suzuki, 1985).

a) There is no precipitation on the start day $t_1$ and the end day $t_2$, nor antecedent precipitation two days before those days.
b) Only days for which the difference of daily discharge rate is less than or equal to $a$% can be selected ($a$ is a numeric criteria defined as the maximum difference in daily discharge rate as shown in Table 2).
c) The period must be between $b$ and $c$ days ($b$ and $c$ are numeric criteria defined as the minimum and maximum days as shown in Table 2).

The first condition is set to remove the quick-flow which has large *dq/dt*, and eliminate the influence of antecedent soil water storage on direct runoff. The second condition is to find the equivalent *q* at times $t_1$ and $t_2$. Periods of less than *b* days (see Table 2) are omitted to minimise fluctuations. If a period is too short, a large variation of daily *ET* is expected. On the other hand, a period greater than or equal to *c* days tends to cause seasonal changes in *ET* undetectable.

For the second condition, Suzuki (1985) used 2% for the difference in discharge rate. However, Murakami *et al*. (2000) and Noguchi *et al*. (2004) used 5% to increase the number of samples. Reported values of *b* and *c* range from 8 to 24 days and 60 to 184 days, respectively for forest sites (Table 2). This study used *a*, *b* and *c* values of 5%, 8 days and 120 days. The *ET* values obtained by SPWB were then averaged on a monthly basis.

Table 2: Criteria for water budget period selection

| Reference | *a* (%) | *b* (days) | *c* (days) |
|---|---|---|---|
| Kuraji and Paul (1994) | 3 & 0.5 | 17 & 24 | 116 |
| Murakami *et al*. (2000) | 5 | 8 | 60 |
| Noguchi *et al*. (2004) | 5 | 8 | 120 |
| Suzuki (1985) | 2 | 8 | 60 |
| Takimoto *et al*. (1994) | - | 15 | 155 & 184 |
| This study | 5 | 8 | 120 |

[1] *a* is the difference in daily discharge rate.
[2] Pairs of $t_1$ and $t_2$ for which the intervening period is less than *b* days or more than *c* days are excluded.
Source: After Noguchi *et al.* (2004)

## *2.4 Catchment Water Balance Method*

The basic water balance equation is $P = Q + ET \pm \Delta S$, where *P* is rainfall, *Q* is runoff and $\Delta S$ is the changes in soil moisture storage. By assuming ΔS is small enough and negligible, *ET* can be estimated from the water balance equation when *Q* and *P* are known. For mean annual water balance computation, it is possible to disregard $\Delta S$, which are difficult to measure and compute. Over a long period, positive and negative water storage variations for individual years tend to cancle off each other, and their net value at the end of a long period may be assumed to be zero (Sokolov and Chapman, 1974).

## 3.0 Results

### *3.1 Climatic Variable*

As expected, the monthly mean air temperature at the study site was very consistent throughout the study period with a difference of only 1.3°C. In contrast, the monthly rainfall varies considerably with maximum in January, which is the end of Northeast Monsoon activity, and May, during inter-monsoon period (Figure 4). The weather condition is relatively dry from the middle of February to end of March but the monthly means relative humidity are always higher than 80%. The highest solar radiations were observed in February and March; 16.09 and 16.04 $MJ.m^{-2}d^{-1}$, respectively.

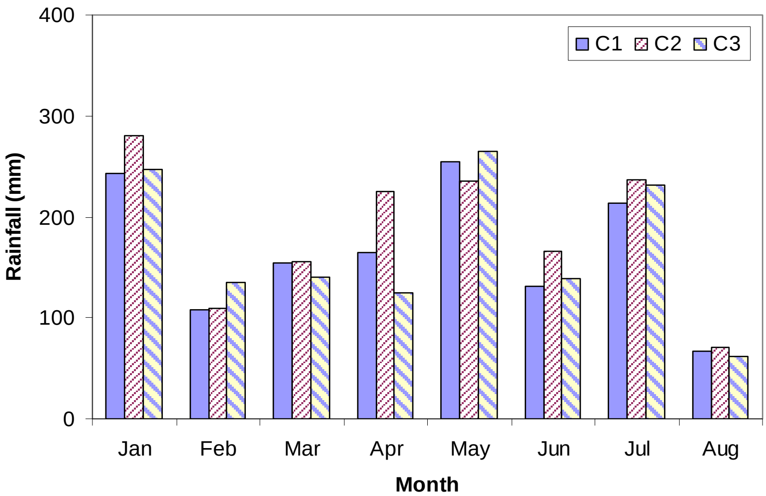


Figure 4: Monthly rainfall in Sedenak catchments between January and August 2006

### *3.2 SPWB Method*

Although SPWB method can estimate *ET* without meteorological data, the model assumptions (see Table 2) have restricted the availability of data for analysis. By adopting no rainfall conditions at the start and end days of analysis, *Pse*=0, we obtained water budget periods from 28 January to 25 August (209 days) for C1, 5 May to 24 August (111 day) for C2, and 27 February to 4 August (158 days) for C3. Based on 5%, 8 days and 120 days criteria for *a*, *b* and *c*, respectively, the analysis produced 33 samples for C1, 13 samples for C2 and 26 samples for C3. With this small number of sample, the data may not be sufficient for the computation of *ET* especially in C2 (see Figure 5b). Alternatively, in order to increase the sample number, *Pse* values of less than 2 mm/day were used. This has resulted in longer water budget periods, from 23 January to 29 August (218 days) for C1, 28 January to 23 August (206 days) for C2 and 16 February to 29 August (195 days) for C3. More importantly the new rainfall threshold (*Pse*<2mm) has increased the number of samples to 170 for C1, 92 for C2 and 100 for C3.

As $t_1$ and $t_2$ can be any day in a month, SPWB method must first computes daily mean *ET* before a monthly *ET* can be estimated. The computed *ET* values with *Pse* = 0 mm and *Pse* < 2 mm for all catchments are shown in Figure 5. The thin lines indicate daily *ET* while the thick line indicates the daily mean *ET*. Since a day may belong to several units of water budget periods, it is possible to have multiple estimates of daily *ET* rate on a same date. These multiple estimates of daily *ET* were then averaged to get a mean daily *ET*. Subsequently, the mean daily *ET* was multiplied by the number of days of the respective months to get monthly *ET* (Figure 6).

In C1, both the daily means *ET* with *Pse* = 0 mm and *Pse* < 2 mm have similar trends and magnitudes (Figure 5). They show rapid increases in the end of January and February. The peaks occurred in March, April and May and decreased again from June. Finally a significant drop occurred in early August. In C2, the estimated daily mean *ET* values with *Pse* < 2 mm are higher than when *Pse* = 0. The trend lines increase rapidly on the 1st March and from thereon the values remain almost constant until it dropped in mid June. Since then, the *ET* fell sharply but increased slightly in the middle of August. The overall daily mean *ET* in C2 is smaller than in C1. For C3, the daily mean *ET* is relatively small throughout the whole water budget period with the lowest of 1.86 mm $d^{-1}$, recorded on the 2nd March. Similar to C1 for *Pse* = 0 mm, the minimum *ET* in C3 occurred in early January and increased when approaching March. The mean *ET* remained constant until early July.

### *3.3 Catchment Water Balance (CWB) Method*

Monthly derived *ET* using the CWB balance method showed large variations, ranging from 25.7 mm/mon for C2 in February to 193.7 mm/mon for C3 in May. February 2006 received relatively low monthly rainfall, 117 mm, compared to the average for all months of 181 mm. During this period, C2 experienced zero flow condition for about 30 days. By omitting the unreasonably low values in the beginning and end of the analysis periods, the means daily *ET* for C1, C2 and C3 are 3.74, 3.29 and 3.01 mm/yr, respectively. These represent projected annual *ET* rates of 1365 mm/yr for C1, 1201 mm/yr for C2 and 1098 mm/day for C3.

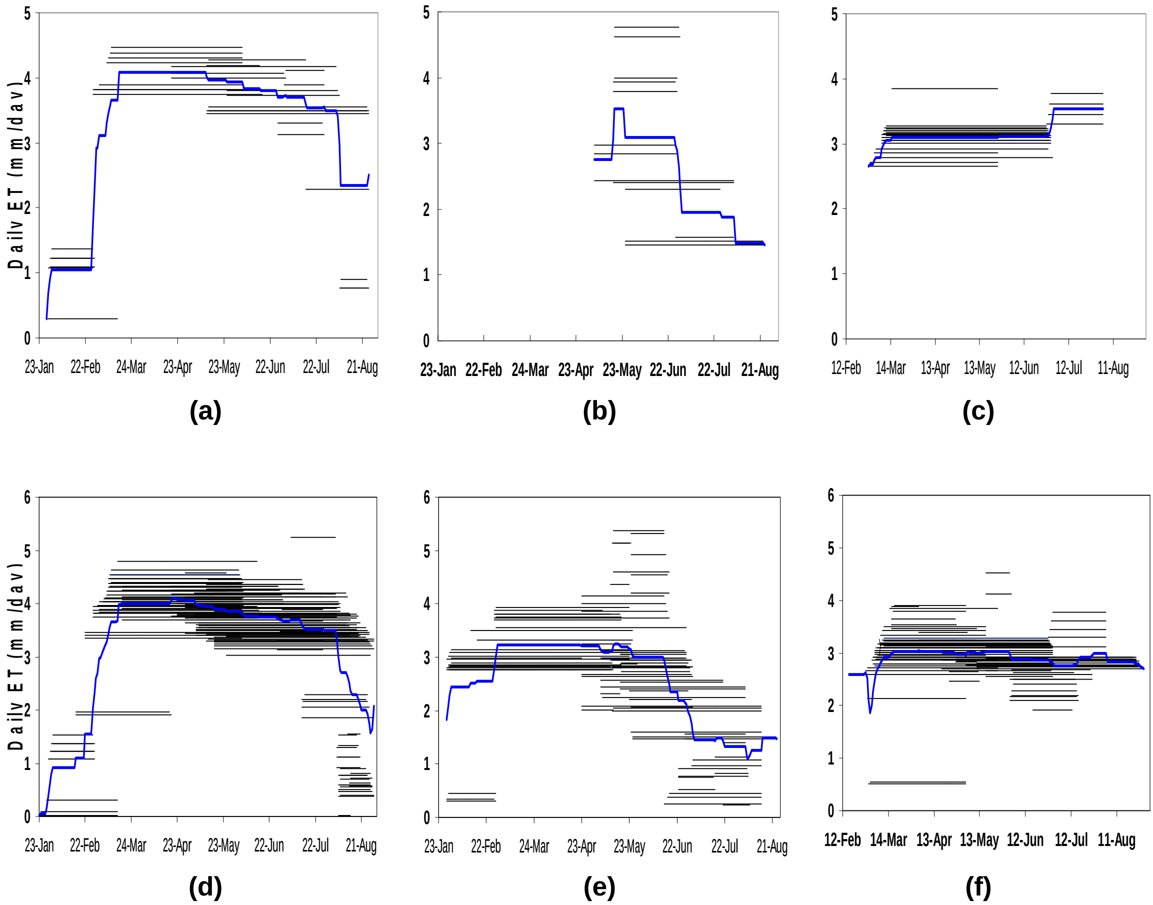


**Figure 5:** Daily *ET* and daily mean *ET* rates derived from SPWB method: *Pse* = 0 mm for (a) C1, (b) C2 and (c) C3; and *Pse* < 2 mm for (d) C1, (e) C2 and (f) C3. The thin lines represent daily *ET* and thick (blue) lines represent daily mean *ET*

## 4.0 Discussion

It is suspected that the SPWB method in the present analysis has underestimated the *ET* especially in the beginning (January and February) and in the end of the analysis periods (August) as the monthly *ET* values for these months are unreasonably low (< 50 mm). Reasons for this are not readily known but could be due to rapid changes in the rainfall patterns which caused sudden rises and drops in the soil moisture. When these low values are omitted, the means daily *ET* for *Pse* = 0 for C1, C2 and C3 are 3.85, 2.54 and 3.17 mm/day, respectively. The means daily *ET* reduced slightly in C1 and C3 when the

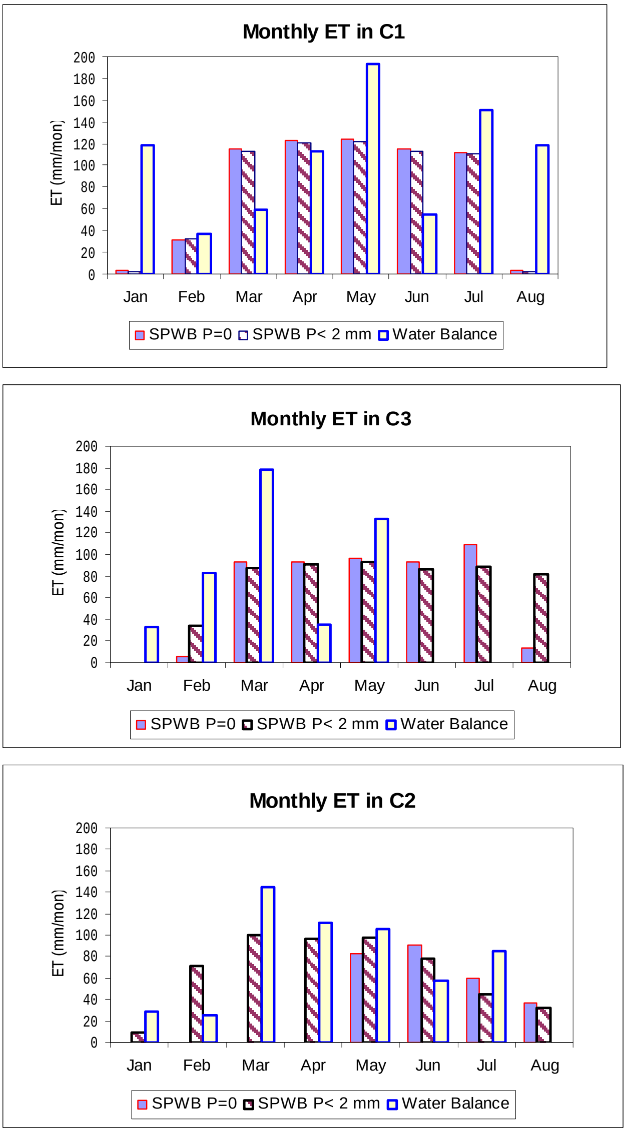


Figure 6 : Monthly *ET* computed by Short Period Water Budget technique with *Pse*=0 mm and *Pse*<2 mm and Catchment Water Balance for C1, C2 and C3.

*Pse* is raised to < 2 mm but vice versa for C2. Despite some differences in the mean daily *ET*, the monthly mean for *Pse* = 0 and *Pse* < 2 mm show very similar trends (Figure 6). The projected annual *ET* derived from mean daily *ET* are 1405, 927, 1157 mm/yr for C1, C2 and C3. These values are quite close with those derived from CWB technique: 1365 mm/yr for C1, 1201 mm/yr for C2 and 1098 mm/day for C3.

While the projected annual *ET* for C1 is reasonable, the *ET* rates for C2 and C3 seem to be grossly underestimated. Reported *ET* values for vegetated catchment in the tropics are mostly confined to forested sites which are expected to have a higher *ET* as tropical forest has larger leave and root biomass, and a much deeper and wider root system. Based on more than 20 catchment studies in the tropics, Bruijnzeel (1990) suggested ballpark *ET* values between 1400 and 1500 mm/yr.

The SPWB method is not applicable when dry or wet days are prevailing. High rainfall was recorded prior and at the beginning of the analysis between November and January. This was followed by dry periods in February and March. Based on site observation, the main stream in C2 had dried up in early March. No rainfall was recorded between 25 February and 11 March and from 13 March to 18 March. The streamflow also decreased rapidly since 25 February as the difference in daily discharge rate, *a*, is 24.5%. The stream remained dry and only returned to low flow level after 28 March. The distinct change in rainfall pattern, from wet to dry has resulted in extremely low *ET* in January when anlysed using SPWP method. Noguchi *et al.* (2004) encountered difficulties in selecting start and end dates when applying the SPWB method under very wet conditions in tropical forest in Selangor, Malaysia. They also found that the SPWB method tends to underestimate *ET* for water budget period extending from wet to dry conditions and vice versa when the water budget period extending from dry to wet conditions.

Problem also arises in applying CWB method when there is distinct dry and wet periods especially for C2 which is the smallest catchment (8.2 ha). The zero flow condition in February indicates a depletion of soil moisture for generating baseflow. A small catchment tends to response more rapidly to wet and dry conditions, causing rapid fluctuation in the soil moisture as well as the *ET* values. Generally, zero flow condition occurs more frequently in small catchments due to limited soil moisture storage (Abdul Rahim and Harding, 1992). In general CWB method is more appropriate to estimate long term *ET* at least on a yearly scale rather than monthly *ET*. Over a long term the net changes in soil moisture storage is usually negligible. Moreover, in CWB method, the data is normally treated based on a hydrological year rather than on a calendar year. In West Malaysia, the hydrological year should start in July and ended in June the following year.

## 5.0 Conclusion

Rates of ET in three oil palm catchments were determined using short-time period water-budget (SPWB) and Catchment Water Balance (CWB) methods. Though all the conditions for running the SPWB are complied, rapid changes in soil water storage may affect the model accuracy. This caused an underestimation of *ET* when the water budget period extends from wet to dry conditions. While the estimates of *ET* in C1 are reasonable, those in C2 and C3 seem to be grossly underestimated. The SPWB method is relatively simple and easy to adopt as it requires less data compared to other *ET* models. However, the selection of water budget periods in the SPWB method can be tricky especially when there are distinct rainy and dry seasons. Setting the rainfall, $Pse < 2$ mm instead of $Pse=0$ at the start and end days can prolong the water budget periods and increase the sample number for analysis. Monthly *ET* values estimated using CWB technique showed more remarkable fluctuation compared to the SPWB method. This is associated with rapid changes in the soil moisture. Thus the CWB method is expected to yield better estimate of *ET* on a long term scale such as yearly. In fact applying CWB method for monthly data can give very misleading results. Except in the beginning and the end of the assessment periods, the SPWB method gave more consistent monthly *ET* compared to CWB method. However, when the *ET* values are projected over a year, both methods gave close values.

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