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Estimating evapotranspiration of irrigated rice at the West Coast of the Peninsular of Malaysia

Schätzung der Evapotranspiration von bewässertem Reis im Bereich der Westküste der Halbinsel von Malaysia

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Stichworte
Evapotranspiration. Schätzmethoden, Reisbewässerung
Keywords
Evapotranspiration, estimation methods, rice irrigation

Zusammenfassung
Die Arbeit berichtet von den Ergebnissen der Schätzung bzw. Berechnung der Evapotranspiration von bewässertem Reis im Bereich der Westküste der Halbinsel von Malaysia. Dabei wurden die Ergebnisse von acht Methoden zur Berechnung der Evapotranspiration geprüft und zwar anhand 30jähriger realer Messergebnisse (Tageswerte).

Die Ergebnisse zeigen bei allen Schätzmethoden den selben Trend. Die höchsten Schätzergebnisse der ET erbringt die Methode von Samani-Hargreaves gefolgt von den Methoden Priestley-Taylor und Hargreaves. Die niedrigsten ET-Werte lieferte die Methode Penman-Monteith gefolgt von den Methoden Blaney-Criddle und die des Verdunstungskessels. Die Differenz der letztgenannten drei Methoden war nicht signifikant. Alle anderen getesteten Methoden unterschieden sich in ihren Ergebnissen signifikant von diesen drei Methoden.

Im Ergebnis kommen die Autoren zu der Schlussfolgerung, dass die Methode Penman-Monteith, die Methode Blaney-Criddle und die Methode Verdunstungskessel für das Untersuchungsgebiet am besten zur Abschätzung der Evapotranspiration geeignet sind. Obwohl mit der Penman Methode die ET überschätzt wird, kann mit ihr eine hinreichend verlässliche Abschätzung der ET erfolgen. Alle anderen Methoden, mit der Tendenz zur Überschätzung, wurden als nicht geeignet für das Untersuchungsgebiet befunden.

Abstract
The correct estimation of ET in the water balance equation allows for improved water management in rice cultivation. Eight evapotranspiration estimation methods (Penman, Penman-Monteith, Pan Evaporation, Kimberly-Penman, Priestley-Taylor, Hargreaves, Samani-Hargreaves and Blaney-Criddle) were tested with 30 years of daily data, in the west coast of peninsular Malaysia. The evapotranspiration estimates by all methods shows the same trend throughout the year. Samani-Hargreaves gives the highest estimates followed by the Priestley-Taylor and Hargreaves methods. The lowest estimates were by Penman-Monteith and followed by the Blaney-Criddle and Pan methods.The Penman-Monteith, Blaney-Criddle and Pan methods estimate lower values

of evapotranspiration with no significant difference among them (P = 0.05). All the other methods are significantly different from these three methods. Penman method, though is different from the three methods, estimates reference evapotranspiration close to these three methods. The Penman-Monteith, Blaney-Criddle and Pan are the best methods to estimate evapotranspiration in the study area. The Penman method can be used to get somewhat reasonable estimates though it overestimates the evapotranspiration a little. All other methods, which tend to over estimate evapotranspiration were not suitable. Comparisons of the selected methods against the Penman-Monteith method showed that they have good correlation. The Pan, Blaney-Criddle and Penman gave correlation coefficients 0.87, 0.55 and 0.97 respectively. A simple correlation equation, developed using 30-year daily data, showed that direct measurement of net radiation can be used to estimate reference evapotranspiration with considerable accuracy (r^2 = 0.97).

1. Introduction

A good estimation of evapotranspiration is vital for proper water management, allowing for improve efficiency of water use, high water productivity and efficient farming activities. Estimates of rice crop evapotranspiration are important in irrigation planning, irrigation scheduling, and overall crop and irrigation system management in large-scale paddy producing areas. Commercial oriented large paddy estates are becoming more and more the norm in Malaysia and examples are the paddy estates Seberang Perak, Endau-Rompin, Kahang and Gedong. Management of these estates constantly seeks out easier ways of management of crop and irrigation systems with an increase in productivity and profit. Most of these large-scale paddy schemes have sufficient experience of crop management, but lack engineers who could help with calculation of crop water requirements and so forth.

Traditionally, reference evapotranspiration is defined as the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water. SMITH et al. (1992) defined the reference evapotranspiration (ET_r) as the rate of evapotranspiration from a hypothetic crop with an assumed crop height (12 cm) and a fixed canopy resistance (70) [s m^{-1}], and albedo (0.23) which would closely resemble evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and not short of water. JENSEN et al. (1990) reported that the reference evapotranspiration is essentially equivalent to potential evapotranspiration, with the exception of the leaf surfaces are typically not wet and a reference crop is specified.

Evapotranspiration can be obtained by many estimation methods. Some of these methods need many weather parameters as inputs while others need fewer. Numerous methods have been developed for evapotranspiration estimation out of which some techniques have been developed partly in response to the availability of data. Factors

such as data availability, the intended use, and the time scale required by the problem must be considered when choosing the evapotranspiration calculation technique (SHIH et al., 1983).

The Penman equation or the later Penman-Monteith equation requires numerous meteorological data parameters and is also complicated. The Penman equations were also limited by the lack of availability of net radiation or solar radiation data. The Penman method requires a variety of climatological data, such as maximum and minimum air temperatures, relative humidity, solar radiation, and wind speed. If some of these data are not available, alternative methods must be used for evapotranspiration estimation. Furthermore, rapid and reliable methods are needed for estimating evapotranspiration for areas in which weather data are not available.

The reference evapotranspiration as determined by the Penman-Monteith approach considers an imaginative crop with fixed parameters and resistance coefficients. ALLEN (1987) found that the Penman-Monteith resistance model provided the most reliable and consistent daily estimates of alfalfa and grass reference evapotranspiration when surface roughness heights and canopy resistances were calculated according to Penman-Monteith equations. The Penman-Monteith has the universal acceptance (McKENNEY and ROSENBERG, 1993 and SMITH et al., 1992). The FAO modified Penman method, which has found worldwide application in irrigation development and management projects are somewhat over predicting under non-advective conditions (SMITH, et al. 1992). Penman-Monteith energy balance equation has become more popular as a method to estimate evapotranspiration as it estimates the flux of energy and moisture between the atmosphere, the land and water surfaces. As it is an energy conservation equation, it is universally accepted. The Penman and Penman-Monteith methods are assumed to be the most reliable because these methods are based on physical principles and because they consider all the climatic factors, which affect reference evapotranspiration. Unanimous agreement was reached in the consultation of FAO in 1990 to recommend the Penman-Monteith approach as the presently best-performing combination equation. Based on comparative studies recently carried out, the method performing best was considered to be the Penman-Monteith method, adopting specific parameters for a standard reference crop (SMITH, et al. 1992). HAZRAT ALI et al. (2000a and 2000b) used Penman-Monteith equation to estimate evapotranspiration because of its universal applicability. They found evapotranspiration estimation by Penman-Monteith equation to be comparable more than 95% with the results observed from pan evaporation data.

Open pans provide a more satisfactory means of estimating potential evapotranspiration and hence evapotranspiration of rice under flooded conditions than any other available technique. A simpler and economic method like pan-evaporation involving 1 or 2 weather parameters with ease in installation, recording and processing and also with reasonable accuracy is comparable to the modified Penman method (Palaskar

et al. 1987). It is also reported that pan evaporation is a more satisfactory method of estimating reference crop evapotranspiration than other methods for rice (AZHAR et al., 1992, SRIBOONLUE and PECHRASKSA, 1992). The pan evaporation method, in comparative studies and for practical irrigation scheduling, is well recognized.

The reliable assumption that temperature is an indicator of the evaporative power of the atmosphere is the basis of temperature-based methods. Although temperature-based methods are useful when data on other meteorological parameters are unavailable, the estimates produced are generally less reliable than those, which take other climatic factors into account. Blaney-Criddle and, to a lesser extent, Hargreaves are most sensitive to temperature change (McKENNY and ROSENBERG, 1993) while their relative sensitivity varies with location and time of year. ROY and AHMED (1999) used Blaney-Criddle method to Selangor state of Malaysia for irrigation simulation of various crops. They did not justify the validity of the Blaney-Criddle to estimate evapotranspiration but used it as a simpler method to estimate it.

McKENNY and ROSENBERG (1993) used Thornthwaite, Blaney-Criddle, Hargreaves, Samani-Hargreaves, Jensen-Haise, Priestley-Taylor, Penman and Penman-Monteith in the North American Great Plains. They found that Thornthwaite produce the lowest annual values and Penman the highest. Jensen-Haise gave relatively low estimates of potential evapotranspiration, followed by Blaney-Criddle, Priestley-Taylor, Hargreaves, and Samani-Hargreaves. The Penman-Monteith method gave values, which are second highest than to those of the other methods. ROSENBERG et al. (1983) and McKENNY and ROSENBERG (1993) reported that Thornthwaite, a highly empirical method, tends to greatly underestimate potential evapotranspiration. CHHABDA et al. (1986) reported that reference evapotranspiration by modified Penman method and by Hargreaves method have been found to be highly significant in Maharashtra, India. Priestley-Taylor has also been found to underestimate potential evapotranspiration, particularly under advective conditions. This equation is similar to the Penman and Penman-Monteith formulations, with the exception that mass transfer effects are represented by a constant value, rather than computed from information on wind speed, humidity, and vegetation characteristics. Gunston and BATCHELOR (1983) applied Priestley-Taylor and Penman methods to estimate evapotranspiration within the latitude zone of 25°N to 25°S. They found that the estimates from these two methods to agree closely when monthly rainfall exceeds monthly evapotranspiration.

YOSHIDA (1979) applied a different approach to develop a simple model where he related the incident solar radiation to the measured evapotranspiration data. He used a value of 0.62 for the ratio of net radiation to total incident radiation. The model was developed in Japan and tested in Los Banos, Philippines and found to predict the evapotranspiration with reasonable accuracy because the weather conditions of both places are more or less the same.

2. Objectives

A method suitable to estimate evapotranspiration in one place does not give the same results when applied to a different place with different climatic conditions. The applicability of different methods to different climatic conditions has given confusing results. Before recommending a method to a particular location, the estimating capability of these methods needs to be verified. Therefore, the main aim of this study is to model evapotranspiration in Seberang Perak paddy estate to find out an easy but accurate approach to estimate evapotranspiration. This study compares the estimated evapotranspiration by Penman (PENMAN, 1948) , Penman-Monteith (MONTEITH, 1965 and 1981), Pan Evaporation, Kimberly-Penman (JENSEN et al. 1990) , Priestley-Taylor (PRIESTLEY and TAYLOR, 1972), Hargreaves (SALAZAR et al., 1984), Samani-Hargreaves (SAMANI and HARGREAVES, 1985) and Blaney-Criddle (ALLEN and PRUITT, 1986). A simple model to estimate reference evapotranspiration is to be developed using long term daily data of direct measurement of net radiation for estimating reference evapotranspiration within the study area.

3. Study area and data

The study area, Seberang Perak paddy estate, is located at 4^0 7'N and 101^0 4' E, and lies 10 km from the west coast of peninsular Malaysia to the southeastern edge of an 80,000 ha flood plain on the right bank of the Perak River. The gross area of the estate is 4482 ha. A government owned agency, the Federal Land Consolidation and Reclamation Authority (FELCRA) manages this paddy estate.

Seberang Perak has a tropical climate characterized by a high rainfall of about 2100 mm with monthly peaks in April and October. Two peak-wet seasons are in March-April (rainfall between 175 – 200mm) and October-November (rainfall between 200 – 300mm). The distinct dry seasons are from December to February (150 - 175 mm) and June to September (less than 150 mm).

Sunshine duration is about 7 hours or more from January to May while it decreases gradually to 5.5 hrs from June to December. Net radiation is 17.0 MJm^{-2} or more from February to September, while the lowest radiation is in November and December. Average air temperature in the project area is little bit above 26ºC. The maximum temperature of the project is about 32ºC and the minimum is about 23ºC, which are more or less uniform throughout the year. Total evaporation in the month, starts to increase from December to March/April reaching a maximum (>110 mm). The monthly minimum is recorded in November, which is less than 100mm.

The climate data for this study were collected from the Sitiawan meteorological station of the Malaysian Meteorological Services. Daily values of data for a period of 30 years (1972 - 2001) were used for this study. The data collected are temperature

(maximum, minimum), relative humidity (maximum, minimum), wind speed, solar radiation, sunshine duration, atmospheric pressure, and pan evaporation.

4. Evaluation of Estimation Methods

Eight methods (Table 1 and Table 2) that are commonly used were selected for this study. Table 1 shows the data needed for these methods while Table 2 shows the model being used. Three (Blaney-Criddle, Hargreaves, and Samani Hargreaves) out of 8 methods used are temperature-based methods. MAIDMENT (1992) reported that the Blaney-Criddle and Hargreaves equations are only recommended for the purpose of evapotranspiration estimation based on temperature. These methods use the mean monthly climatic values, which were calculated using the daily values. Hargreaves, and Samani Hargreaves methods require information on latitude and time of year to represent latitudinal and seasonal variation in incoming solar radiation. Blaney-Criddle (ALLEN and PRUITT 1986) method used in this study is hard to consider merely as a temperature based method (MAIDMENT, 1992). This form of the Blaney-Criddle method uses temperature, minimum relative humidity, daytime wind speed and day length, which is a function of latitude and time of year.

Table 1:
Data requirements of selected formulae

Method	T	R_s	RH	U	n	P	D	Temporal Resolution of Data
Pan Method			X*	X*			X	Daily
Penman	X	X	X	X		X		Daily
Penman-Monteith	X	X	X	X		X		Daily
Kimberly-Penman	X	X		X		X		Daily
Priestley-Taylor	X	X						Daily
Hargreaves	X							Monthly
Samani-Hargreaves	X							Monthly
Blaney-Criddle	X		X	X	X			Monthly

* Needed to calculate pan coefficient
D - Pan evaporation, n - sunshine hours, P - atmospheric pressure, RH - relative humidity, R_s - solar radiation, T - temperature, U - wind speed.

Table 2:
Methods used to estimate reference evapotranspiration

Method	Formula Applied
Pan Method Pan Coefficient (Allen et al., 1998)	$ET_r = K_p E_{pan}$ $K_p = 0.108 - 0.0286U_2 + 0.0422\ln(FET) + 0.1434\ln(RH_m)$ $- 0.000631[\ln(FET)]^2 \ln(RH_m)$
Penman (Penman, 1948)	$ET_r = \frac{\Delta(R_n - G) + \gamma 6.43 f(u)(e_a - e_d)}{\Delta + \gamma}$
Penman-Monteith (Monteith, 1965 and 1981)	$ET_r = \frac{\Delta(R_n - G) + \frac{\rho_a C_p (e_a - e_d)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_c}{r_a}\right)}$
Kimberly-Penman (Jensen et al. 1990)	$ET_r = \frac{\Delta(R_n - G)}{\Delta + \gamma} + \frac{\gamma}{\Delta + \gamma}\frac{6.43 W_f D}{\lambda}$
Priestley-Taylor (Priestley and Taylor, 1972)	$ET_r = 1.26\frac{\Delta(R_n - G)}{\Delta + \gamma}$
Hargreaves (Salazar et al., 1984)	$ET_r = 0.0038\ R_a T (\partial T)^{0.5}$
Samani-Hargreaves (Samani and Hargreaves, 1985)	$ET_r = 0.00094\ S_o \partial T_f T_f$
Blaney-Criddle (Allen et al. 1986)	$ET_r = a_{BC} + b_{BC} f$ $f = p(0.46T + 8.13)$ $a_{BC} = 0.0043(RH_{\min}) - (n/N) - 1.41$ $b_{BC} = 0.82 - 0.0041(RH_{\min}) + 1.07(n/N) + 0.066(U_d)$ $-0.006(RH_{\min})(n/N) - 0.0006(RH_{\min})(U_d)$

Legend

ET_r is reference evapotranspiration (mm/day), K_p is pan coefficient, U_2 is average daily wind speed at 2m height (ms^{-1}), RH_m is average daily relative humidity (%), FET is fetch, E_{pan} is pan evaporation (mm), Δ is gradient of saturation vapor pressure temperature function (kPa^oC^{-1}), R_n is the net radiation (MJ m^{-2} day^{-1}), G is soil heat flux (MJ m^{-2} day^{-1}), ρa is air density (kg/m^3), C_p is specific heat of the air at constant pressure (kJ kg^{-1} K^{-1}), e_a is the saturation vapor pressure (kP_a), e_d saturation vapor pressure at dew point temperature (kP_a), γ is the psychrometric constant (kPa^oC^{-1}), f(u) is an empirical win speed function, r_a is aerodynamic resistance to water vapor diffusion into the atmospheric boundary layer (s m^{-1}), r_c is the vegetation canopy resistance to water vapor transfer (s m^{-1}), W_f is a wind function., λ is latent heat of vaporization of water (MJ kg^{-1}), R_a is extraterrestrial radiation expressed in equivalent evaporation (mm/day), T is mean air temperature (^oC), ∂T is the difference between mean monthly maximum and mean monthly minimum temperatures (^oC), S_o is water equivalent of extraterrestrial radiation (mm/day), ∂T_f is the difference between mean monthly maximum and mean monthly minimum temperatures (^oF), T_f is mean temperature (^oF), a_{BC}, b_{BC} and f are functions, (n/N) is the ratio of actual to possible sunshine hours, RH_{min} is minimum daily relative humidity, p is the ratio of actual daily daytime hours to annual men daily daytime hours, U_d is the daytime wind at 2 m height in m/s.

The Penman (PENMAN, 1948), Penman-Monteith (MONTEITH, 1965 and 1981), Kimberly-Penman (JENSEN et al., 1990) and Priestley-Taylor (PRIESTLEY and TAYLOR, 1972) equations are all known as 'combination methods' because they combine the effects of both radiation and mass transfer on reference evapotranspiration. These equations have different tuning of the diffusion component that has little universal advantage (MAIDMENT, 1992). The differences among these equations lie in the computation of the term that accounts for mass transfer effects. The Penman method uses vapor pressure deficit that is a function of temperature and actual vapor pressure and an empirical wind speed function. Priestley-Taylor is a simplified combination equation, which uses an empirical coefficient to account for mass transfer effects. Penman-Monteith is the most soundly based on physical principles. Penman-Monteith includes both climatic and vegetation characteristics in quantifying mass transfer effects. It is also the most data demanding, requiring information on temperature, radiation, humidity and wind speed, as well as on various characteristics of the vegetation.

The daily reference evapotranspiration is estimated by Penman (PENMAN, 1948), Penman-Monteith (MONTEITH, 1964 and 1981), Kimberly-Penman (JENSEN et al., 1990) and Priestley-Taylor (PRIESTLEY and TAYLOR, 1972) and Pan methods. The daily values for the 30 years were used to calculate the monthly averages. In the case of the Pan evaporation, the pan coefficient, K_p values were calculated based on FAO irrigation and drainage paper 56 (ALLEN, et al., 1998). Blaney-Criddle (ALLEN and PRUITT, 1986), Hargreaves (SALAZAR et al., 1984), and Samani Hargreaves (SAMANI and HARGREAVES, 1985) equations were used to calculate the monthly reference evapotranspiration values. Monthly average values needed for these three methods were calculated from the available daily data.

5. Results and Discussions

Figure 1 shows the monthly average reference evapotranspiration values by different methods for the study area. Most of these methods show the same trend throughout the year. The Samani-Hargreaves estimated the highest reference evapotranspiration for all the months and Priestley-Taylor method followed next. The reference evapotranspiration estimates for the months June, August, September and November were less than the Hargreaves method while in July it was less than the estimate by Kimberly-Penman. This variation in June to November could be due to low radiation and sunshine hours.

The present study area gets an average monthly rainfall greater than the evapotranspiration for all the months. But the Priestley-Taylor method does not estimate evapotranspiration that is agreeable with Penman methods. Therefore, Priestley-Taylor method is not suitable for the west coast of Malaysia for accurate estimation

of the evapotranspiration. This over estimation by Priestley-Taylor method may be because of the high humidity with low wind speeds that force the ratio of the aerodynamic to energy terms below 0.26.

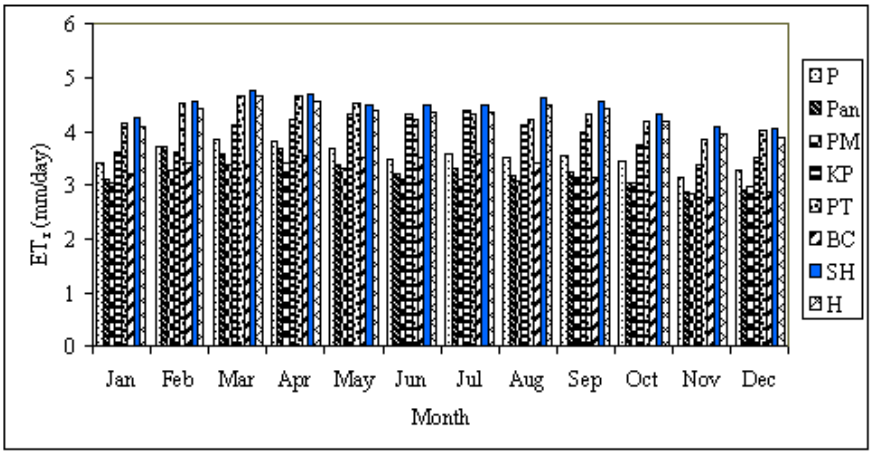

Figure 1:
Monthly average reference evapotranspiration for the study area

Figure 2 shows the mean reference evapotranspiration and annual evapotranspiration values estimated by different methods for the study area. Reference evapotranspiration and annual evapotranspiration estimates show the same pattern. The Samani-Hargreaves gives the highest estimate while Penman-Monteith the lowest value.

The monthly averages of the evapotranspiration estimates by all the eight methods were tested with a Randomized Complete Block Design where each method is taken as treatments and the month as blocks. A mean separation procedure was done to verify the differences between different methods of estimations. The results by a two-way ANOVA are given in Table 3. The methods Blaney-Criddle, Pan and Penman-Monteith are giving lowest values and there are no significant differences among them (P = 0.05). All other five methods are significantly different from Blaney-Criddle, Pan and Penman-Monteith methods. The estimates of Penman, Kimberly Penman and Priestley-Taylor methods significantly differ from each other. The methods Hargreaves and Samani-Hargreaves give the highest values. These two methods do not have any significant differences among them (P=0.05).

According to the results in Table 3, the methods of Blaney-Criddle, Pan and Penman-Monteith are suitable for the study area and to the west coast of peninsular Malaysia where the climatic conditions are the same. Therefore, the methods, which have significant agreement with the results of the Penman-Monteith, could also be

used satisfactorily to estimate reference evapotranspiration for the study area. The estimation of evapotranspiration using pan needs pan evaporation and average relative humidity and wind speed to calculate the pan coefficient. The original Blaney-Criddle method needs average temperature but the form used in this study needs average temperature together with minimum relative humidity, sunshine hour and wind speed. Therefore, it is now hard to consider the method as a temperature based method. The pan and Blaney-Criddle methods are equally suitable to the study area and the west coast of peninsular Malaysia as the complex and data demanding Penman-Monteith to estimate reference evapotranspiration.

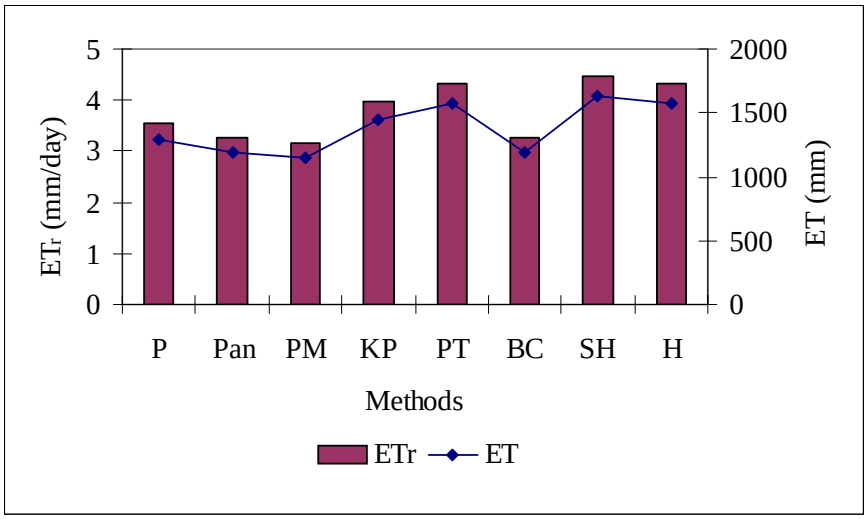

Figure 2:
Mean reference evapotranspiration and annual evapotranspiration for Seberang Perak

The Pan method needs only the depth of daily evaporation together with wind speed and relative humidity to calculate the pan coefficient. The Blaney-Criddle used in this study needs mean monthly temperature, mean minimum relative humidity and mean daytime wind speed at 2 m height. As these equations need only few input data and are monthly averages in the case of Blaney-Criddle, it is much more convenient to use. If more precise information on evapotranspiration is required, then it is more suitable to use the Penman-Monteith equation.

The Penman method is also suitable for the purpose of estimating the reference evapotranspiration but it over estimated it little. This could be because of the empirical wind function used in the equation. This wind function takes many different forms

in literature. Kimberly-Penman, Priestley-Taylor, Hargreaves and Samani-Hargreaves are over estimating the reference evapotranspiration. Therefore, these methods are not suitable to estimate reference evapotranspiration for the study area and west coast of peninsular Malaysia where the climatic conditions are the same. In the west coast of peninsular Malaysia, Penman-Monteith gave the lowest estimates of reference evapotranspiration, followed by Pan method, Blaney-Criddle and Penman method.

Table 3:
Comparison of evapotranspiration estimation methods

Evapotranspiration estimation method	Mean*
Blaney-Criddle	3.276 a
Hargreaves	4.486 e
Kimberly-Penman	3.989 b
Pan	3.229 a
Penman	3.550 c
Penman Monteith	3.152 a
Priestley-Taylor	4.329 d
Samani-Hargreaves	4.454 e

*Values followed by the same letter are not significantly different at P = 0.05

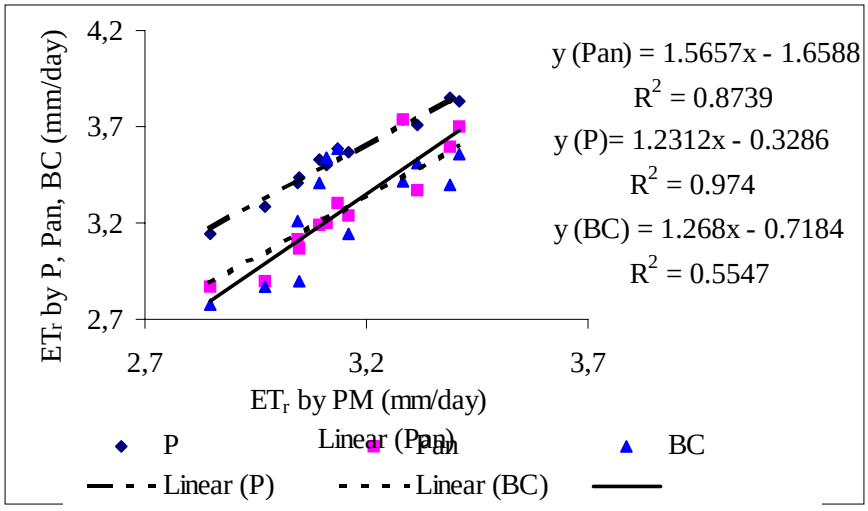

Figure 3:
Correlation between reference evapotranspiration (ET_r) from Penman-Monteith, and Pan, Blaney-Criddle and Penman methods

A simple correlation between the pan evapotranspiration, Penman and Blaney-Criddle with Penman-Monteith are shown in Figure 3. A highly significant correlation coefficient of 0.87 was observed between Pan and Penman-Monteith while the correlation is lower for Blaney-Criddle method. PALASKAR et al. (1987) compared pan evaporation and modified Penman methods in India and found that these two to have strong correlations. Therefore, the bigger paddy estates such as Seberang Perak can install its own Class A pans as it will give better measurement of evaporation and estimates of evapotranspiration for water management in paddy estates.

The present study shows that the Penman-Monteith has a higher correlation with the Pan evapotranspiration with accuracy greater than 95% for the west coast of Malaysia. Throughout the year, the Penman-Monteith under predicts the evapotranspiration when it is compared with the Pan evapotranspiration estimates. In the Muda scheme, the Penman-Monteith estimates were under predicted only from September to March. The comparison with the Pan evapotranspiration showed accuracy more than 95%.

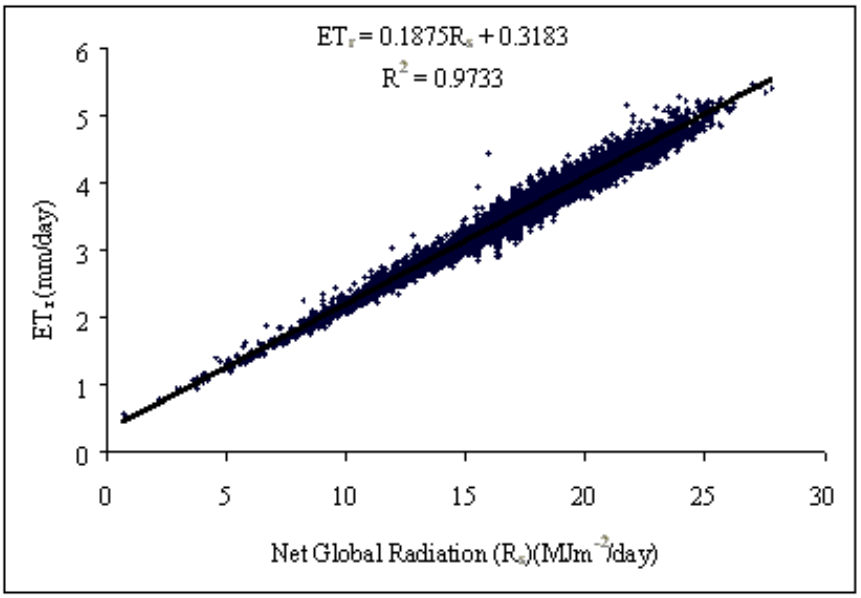

Figure 4:
Relationship between measured net global radiation and reference evapotranspiration by Penman-Monteith method

The water loss from a crop is related to the incident solar energy. There is a need for a simple model that relates solar radiation to evapotranspiration. By relating the measured net global radiation from the study area to the estimated reference evapotranspiration, a simple model was developed using 30 years of observed data. The equation shown in Figure 4 gives a high correlation (0.97) between the net global radiation and evapotranspiration. This simple model can be used for the study area to reasonably estimate reference crop evapotranspiration with only the measured net global radiation rather than using a very complex Penman-Monteith model. The proposed simple model needs to be further verified if it to be applied eslwhere in Peninsular Malaysia.

6. Conclusion

In this study, eight evapotranspiration estimation methods (Penman (PENMAN, 1948) , Penman-Monteith (MONTEITH, 1965 and 1981), Pan Evaporation, Kimberly-Penman (JENSEN et al., 1990) , Priestley-Taylor (PRIESTLEY and TAYLOR, 1972), Hargreaves (SALAZAR et al., 1984), Samani-Hargreaves (SAMANI and HARGREAVES, 1985) and Blaney-Criddle (ALLEN and PRUITT, 1986)) were tested with 30 years of daily data. The data used in this study are temperature, relative humidity, wind speed, solar radiation, sunshine duration, atmospheric pressure, and pan evaporation.

The evapotranspiration estimates by all these methods shows the same trend throughout the year. The annual estimated evapotranspiration also shows the same trend for all the methods. Samani-Hargreaves gives the highest estimates followed by Priestley-Taylor and Hargreaves methods. The lowest estimates were by Penman-Monteith and followed by Blaney-Criddle and Pan methods.

The final results of these estimates were checked statistically and found that Penman-Monteith, Blaney-Criddle and Pan methods to estimate lower values of evapotranspiration with no significant difference among them ($P = 0.05$). All the other methods are significantly different from these three methods. Penman method, though is different from the three methods, estimates reference evapotranspiration close to these three methods. Therefore, the Penman-Monteith, Blaney-Criddle and Pan are the best methods to estimate evapotranspiration to the study area and the west coast of peninsular Malaysia while Penman method can be used to get somewhat reasonable estimates. Penman method overestimates the evapotranspiration little bit. All other methods, which over estimate evapotranspiration, are not suitable for the study area.

The comparison of the three selected methods with Penman-Monteith show that they have good correlation where Pan, Blaney-Criddle and Penman giving correlation coefficients 0.87, 0.55 and 0.97 respectively.

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