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Estimation of Evapotranspiration in a Rice Irrigation Scheme in Peninsular Malaysia

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ABSTRAK

Taksiran penyejatpeluhan yang betul dalam persamaan perseimbangan air adalah untuk pengurusan air tanaman padi diperbaiki. Lapan kaedah taksiran penyejatpeluhan (Penman, Penman-Monteith, Pan Evaporation, Kimberly-Penman, Priestley-Taylor, Hargreaves, Samani-Hargreaves and Blaney-Criddle) diujikan dengan 30 tahun data harian, di satu tapak di pantai barat Semenanjung Malaysia. Taksiran penyejatpeluhan semua kaedah menunjukkan tren yang sama sepanjang tahun. Kaedah Samani-Hargreaves menghasilkan taksiran terbesar, diikuti oleh kaedah Priestley-Taylor dan Hargreaves. Taksiran penyejatpeluhan terkecil dihasilkan oleh kaedah the Penman-Monteith, diikuti oleh kaedah-kaedah Blaney-Cridle dan Panji. Ketiga-tiga kaedah ini menghasilkan nilai penyejatpeluhan rendah tanpa perbezaan bererti di antaranya (P = 0.05). Semua kaedah taksiran lain berbeza bererti daripada ketiga-tiga kaedah tersebut. Kaedah Penman, walaupun berbeza daripada ketiga-tiga kaedah itu dari segi perkembangan, akan tetapi menaksirkan penyejatpeluhan rapat dengan ketiga-tiga kaedah. Kaedah Penman-Monteith, Blaney-Criddle dan Panci adalah lebih baik demi untuk menaksirkan penyejatpeluhan di kawasan kajian. Keputusan daripada kajian ini menunjukkan bahawa kaedah Penman boleh digunakan demi untuk menghasilkan taksiran yang memuaskan walaupun ia menaksir penyejatpeluhan lebih besar. Perbandingan di antara kaedah-kaedah terpilih ini dengan kaedah Penman-Monteith menunjukkan sekaitan baik. Kaedah Pan, Blaney-Criddle dan Penman menghasilkan pekali sekaitan 0.87, 0.55 dan 0.97 masing-masing. Sebuah persamaan sekaitan mudah yang dibangunkan berdasarkan data harian sepanjang 30 tahun, menunjukkan bahawa ukuran terus sinaran boleh digunakan untuk taksiran penyejatpeluhan rujukan dengan kejituan yang berlebihan ($r^2 = 0.97$).

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, at a study site in the west coast of Peninsular Malaysia. The estimation of evapotranspiration by all methods showed the same trend throughout the year. The Samani-Hargreaves method gave the highest estimation followed by the Priestley-Taylor and Hargreaves methods. The Penman-Monteith method gave the lowest estimations of evapotranspiration followed by the Blaney-Criddle method and then the Pan method. The

Penman-Monteith, Blaney-Criddle and Pan methods gave lower values of evapotranspiration with no significant difference among them (P = 0.05). All the other estimation methods were significantly different from these three methods. The Penman method, though was different from the three methods in terms of development; however, it estimates evapotranspiration close to these three methods. The Penman-Monteith, Blaney-Criddle and Pan were found to be the better methods to estimate evapotranspiration in the study area. Results from this study showed that the Penman method can be used to get somewhat reasonable estimates though it tends to overestimate evapotranspiration. Comparisons of these selected methods against the Penman-Monteith method showed that they have good correlation. The Pan, Blaney-Criddle and Penman gave correlation coefficients of 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).

Keywords: Evapotranspiration, estimation methods, rice irrigation

INTRODUCTION

A good estimation of evapotranspiration is vital for proper water management as it allows for improved efficiency of water use, high water productivity and efficient farming activities. Estimation of rice crop evapotranspiration is important in irrigation planning, irrigation scheduling, and overall crop and irrigation system management in large-scale rice producing areas. Commercial oriented large rice estates are becoming more and more the norm in Malaysia and examples are the rice estates in Seberang Perak, Endau-Rompin, Kahang and Gedong. The management of these estates constantly seeks out easier ways of management of crop and irrigation systems with the aim of increasing productivity and profit. Most of these large-scale rice schemes have sufficient experience of crop management, but lack engineers who could help compute crop water requirements.

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 reference evapotranspiration is essentially equivalent to potential evapotranspiration, with the exception of the leaf surfaces being 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 less parameters. Of the numerous methods developed for evapotranspiration estimation, 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 and the Penman-Monteith equation require numerous meteorological data parameters and are also complicated. The Penman equations are 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 estimation of evapotranspiration. 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 the Penman-Monteith equations. The Penman-Monteith has universal acceptance (McKenney and Rosenberg, 1993 and Smith *et al.* 1992). The Food and Agricultural Organization modified Penman method, which has found worldwide application in irrigation development and management projects, is somewhat over predictive under non-advective conditions (Smith *et al.* 1992). The 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, 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 they consider all the climatic factors which affect reference evapotranspiration. Unanimous agreement was reached in the consultation of FAO in 1998 to recommend the Penman-Monteith approach as the presently best-performing combination equation (Allen *et al.* 1998). Based on comparative studies recently carried out, the best performing method was considered to be the Penman-Monteith method, under specific parameters for a standard reference crop (Smith *et al.* 1992). Hazrat Ali *et al.* (2000a; 2000b) used Penman-Monteith equation to estimate evapotranspiration because of its universal applicability. They found evapotranspiration estimation by Penman-Monteith equation to be comparable with the results observed from pan evaporation data in more than 95% of the cases.

Open pans provide a more satisfactory means of estimating potential evapotranspiration and hence evapotranspiration of rice under flooded conditions compared to 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 recognised.

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 for 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 (1974) 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 the Blaney-Criddle method to the state of Selangor in 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 produced the lowest annual values and Penman the highest. Jensen-Haise gave relatively low estimation of evapotranspiration, followed by Blaney-Criddle, Priestley-Taylor, Hargreaves, and Samani-Hargreaves. Of the methods, the Penman-Monteith method gave values, which were second highest. 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 has been found to be highly significant in Maharashtra, India. Priestley and Taylor (1972) 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 exceeded 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.

OBJECTIVES

A method suitable for estimation of evapotranspiration in one place does not give the same results when applied to a different place with different climatic conditions. The application 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 rice 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; 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). From this comparison, 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.

STUDY AREA AND DATA

The study area, Seberang Perak rice 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 rice estate.

Seberang Perak has a tropical climate characterised by a high annual rainfall of about 2100 mm with monthly peaks in April and October. Two peak-wet seasons are in March-April (rainfall between 175 – 200 mm) and October-November (rainfall between 200 – 300 mm). 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 hours 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 a little bit above 26°C. The maximum temperature in the project area is about 32°C and the minimum is about 23°C, that is 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 100 mm.

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

EVALUATION OF ESTIMATION METHODS

Eight methods that are commonly used were selected for this study. Table 1 shows the data needed for these methods while Table 2 shows the model used. Three (Blaney-Criddle, Hargreaves, and Samani Hargreaves) of the eight 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.

The Penman (Penman 1948), Penman-Monteith (Monteith 1965; 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 1965; 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.

TABLE 1
Methods used to estimate reference evapotranspiration

Method	Formula applied
Pan Method	$ET_r = K_p E_{pan}$
Pan Coefficient (Allen *et al.* 1998)	$K_p = 0.108 - 0.0286U_2 + 0.0422\ \ln(FET) + 0.143\ \ln(RH_m) - 0.000631[\ln(FET)]^2\ \ln(RH_m)$
Penman (Penman 1948)	$ET_r = \dfrac{\Delta(R_n - G) + \gamma 6.43 f(u)(e_a - e_d)}{\Delta + \gamma}$
Penman-Monteith (Monteith 1965; 1981)	$ET_r = \dfrac{\Delta(R_n - G) + \dfrac{\rho_a C_p (e_a - e_d)}{r_a}}{\Delta + \gamma\left(1 + \dfrac{r_c}{r_a}\right)}$
Kimberly-Penman (Jensen *et al.* 1990)	$ET_r = \dfrac{\Delta(R_n - G)}{\Delta + \gamma} + \dfrac{\gamma}{\Delta + \gamma}\dfrac{6.43 W_f D}{\lambda}$
Priestley-Taylor (Priestley and Taylor 1972)	$ET_r = 1.26\dfrac{\Delta(R_n - G)}{\Delta + \gamma}$
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)	$ET_r = aBC + b_{BC} f$ $f = p(0.46T + 8.13)$ $a_{BC} = 0.0043(RH_{min}) - (n/N) - 1.41$ $b_{BC} = 0.82 - 0.0041(RH_{min}) + 1.07\ (n/N) + 0.066(U_d) - 0.006(RH_{min})(n/N) - 0.0006(n/N)(U_d)$

ET_r is reference evapotranspiration (mm/day), K_p is pan coefficient, U_2 is average daily wind speed at 2 m height (ms^{-1}), RH_m is average daily relative humidity (%), FET is fetch (m), E_{pan} is pan evaporation (mm), Δ is gradient of saturation vapor pressure temperature function (kPa°C^{-1}), R_n is the net radiation (MJ m^{-2} day^{-1}), G is soil heat flux (MJ m^{-2} day^{-1}), r_a 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°C^{-1}), $f(u)$ is an empirical wind 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 (°C), ∂T is the difference between mean monthly maximum and mean monthly minimum temperatures (°C), S_o is water equivalent of

Table 1 (*cont'd*)
extraterrestrial radiation (mm/day), ∂T_f is the difference between mean monthly maximum and mean monthly minimum temperatures (°F), T_f is mean temperature (°F), 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.

TABLE 2
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

* Need 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.

RESULTS AND DISCUSSION

Fig. 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 of 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 study area gets an average monthly rainfall greater than the evapotranspiration for all the months. The Priestley-Taylor method was not in agreement 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 the high humidity with low wind speeds resulted in the ratio of the aerodynamic to energy terms to be below 0.26.

Fig. 2 shows the mean reference evapotranspiration, ET_r and annual evapotranspiration, ET, 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.

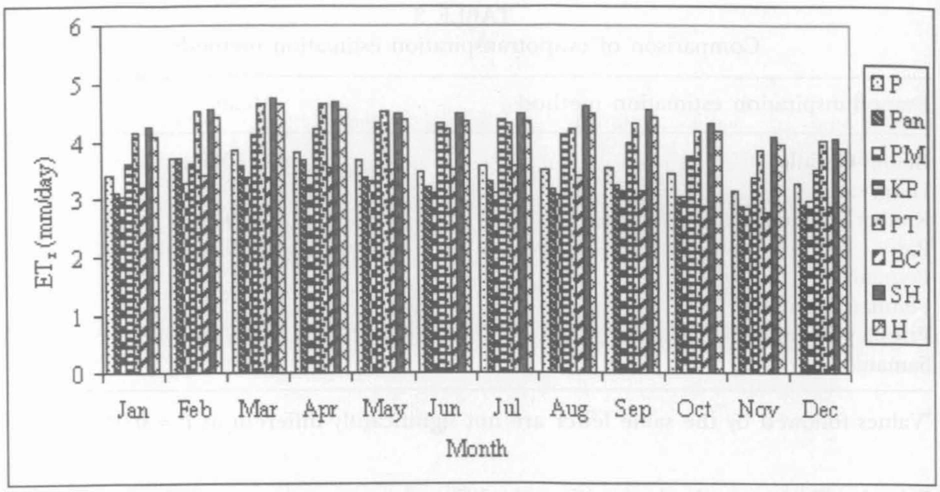

Fig. 1: Monthly average reference evapotranspiration for the study area. The methods are P for Penman, Pan for Pan Evaporation, PM for Penman Monteith, KP for Kimberly-Priestley, PT for Priestley-Taylor, BC for Blaney Criddle, SH for Samani-Hargreaves and H for Hargreaves

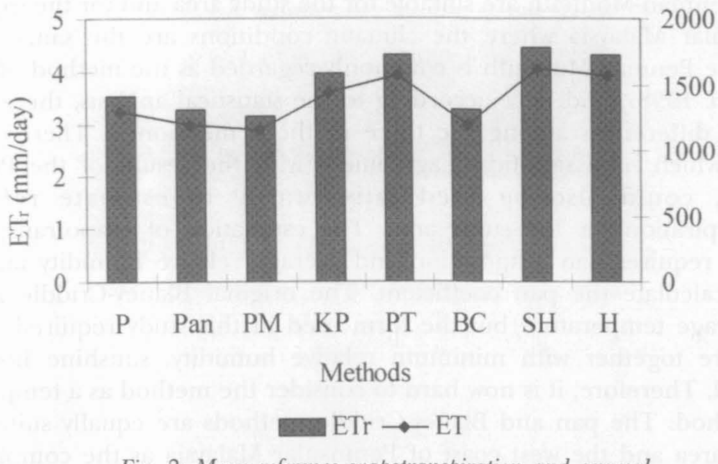

Fig. 2: Mean reference evapotranspiration and annual evapotranspiration for Seberang Perak

The monthly averages of the evapotranspiration estimates by all the eight methods were tested with a Randomized Complete Block Design where each method was taken as treatment 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 Analysis of Variances are given in Table 3. The methods, Blaney-Criddle, Pan and Penman-Monteith, gave the lowest of values and there were no significant differences among them ($P = 0.05$). All other five methods were significantly different from Blaney-Criddle, Pan and Penman-Monteith methods. The estimates of Penman, Kimberly Penman and

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

Priestley-Taylor methods significantly differed from each other. The methods of Hargreaves and Samani-Hargreaves gave the highest values. These two methods do not have any significant differences among them (P=0.05).

According to the results shown in Table 3, the methods of Blaney-Criddle, Pan and Penman-Monteith are suitable for the study area and for the west coast of Peninsular Malaysia where the climatic conditions are the same. This is because the Penman-Monteith is commonly regarded as the method of choice (Allen *et al.* 1998), and here according to the statistical analysis, there are no significant differences among the three methods mentioned. 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 requires 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 required 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 for the study area and the west coast of Peninsular Malaysia as the complex and data demanding Penman-Monteith to estimate reference evapotranspiration.

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 for 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 this method tends to over-estimate it slightly.

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 have over estimated 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.

A simple correlation between the pan evapotranspiration, Penman and Blaney-Criddle with Penman-Monteith is shown in *Fig. 3.* A highly significant correlation coefficient of 0.87 was observed between Pan and Penman-Monteith while the correlation was lower for Blaney-Criddle method. Palaskar *et al.* (1987) compared pan evaporation and modified Penman methods in India and found these two to have strong correlations. Therefore, the bigger rice estates such as Seberang Perak can install their own Class A pans as it will give better measurement of evaporation and estimates of evapotranspiration for water management in rice 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 predicted 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 (Hazrat *et al.* 2000a). The comparison with the Pan evapotranspiration showed an accuracy of more than 95%.

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

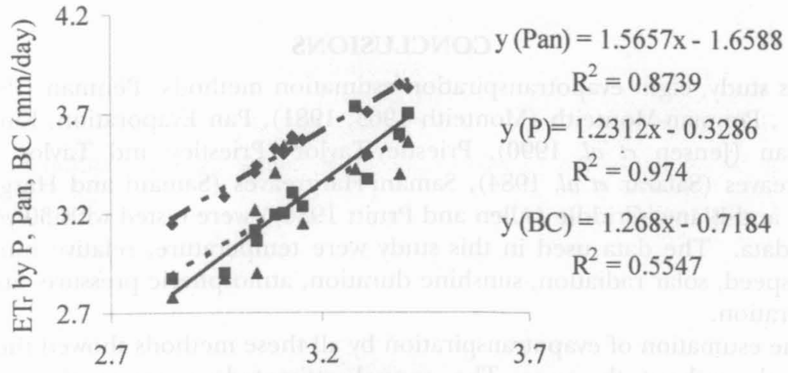

Fig. 3: Correlation between reference evapotranspiration (ET_r) from Penman-Monteith, and Pan, Blaney-Criddle and Penman methods

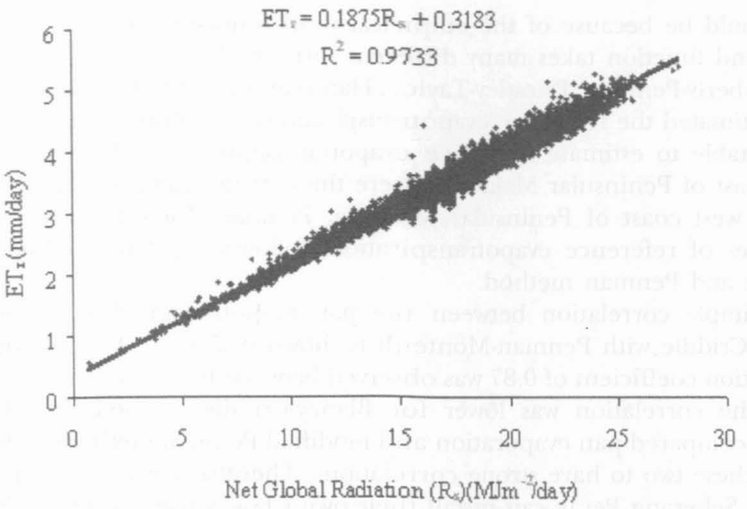

Fig. 4: Relationship between measured net global radiation and reference evapotranspiration by Penman-Monteith method

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 *Fig. 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 however, needs to be further verified if it is to be applied elsewhere in Peninsular Malaysia.

CONCLUSIONS

In this study, eight evapotranspiration estimation methods (Penman (Penman 1948) , Penman-Monteith (Monteith 1965; 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 were temperature, relative humidity, wind speed, solar radiation, sunshine duration, atmospheric pressure, and pan evaporation.

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

The final results of the estimation were checked statistically and it was found that the Penman-Monteith, Blaney-Criddle and Pan methods gave lower values of evapotranspiration with no significant difference among them (P = 0.05). All the other methods were significantly different from these three methods. The Penman method, though different from the three methods, estimated reference evapotranspiration close to these three methods. Therefore, the Penman-Monteith, Blaney-Criddle and Pan are the better methods to estimate evapotranspiration for the study area and the west coast of Peninsular Malaysia while Penman method can be used to get somewhat reasonable estimations. Penman method overestimates evapotranspiration. All other methods, which over estimate evapotranspiration, are not recommended for the study area.

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

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