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Modelling of Changes in Evapotranspiration for an Area in Peninsular Malaysia

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ABSTRAK

Satu kajian telah dijalankan untuk menyemakkan kepekaan taksiran penyejatpeluhan disebabkan perubahan iklim. Kajian ini menggunakan data 30 tahun daripada stesyen meteorologi terletak di estet padi FELCRA, Seberang Perak, Semenanjung Malaysia. Kesan disebabkan perubahan pembolehubah iklim, suhu, sinaran suria, kelembapan nisbi dan laju angin terhadap penyejatpeluhan dianalisis. Keputusan menunjukkan bahawa suhu min, kelembapan nisbi min, laju angin min dan sinaran sejagat berubah +0.182 °C, -0.73%, -0.0365 m/s dan +0.146 MJ/m^2 sedekad masing-masing. Analisis statistik taksiran penyejatpeluhan hasil kaedah-kaedah terpilih menunjukkan bahawa kaedah-kaedah Penman-Monteith, Blaney-Criddle dan kaedah penyejatan Pan adalah taksiran serupa (P=0.05) dan adalah sesuai untuk kawasan kajian. Bila perubahan pada iklim sekarang dikuatkuasakan pada dekad-dekad akan datang, kadar taksiran melebihi berbentuk linear bagi kaedah-kaedah Blaney-Criddle dan Penman, sebaliknya merupa eksponen bagi kaedah Penman-Monteith. Tokohan keseluruhan yang dijangka selepas 5 dekad ialah 5.3% dan 6.9% bagi kaedah-kaedah Penman dan Blaney-Criddle masing-masing. Kaedah Penman-Monteith meramalkan tokohan penyejatpeluhan sebanyak 74.4% pada lima dekad akan datang.

ABSTRACT

A study was carried out to check the sensitivity of evapotranspiration estimation due to changes in climate. The study used 30 years of data from the meteorological station in the FELCRA paddy estate, Seberang Perak, Peninsular Malaysia. The effect of changes in the climatic variables, temperature, solar radiation, relative humidity and wind speed on evapotranspiration were analyzed. Results showed that the mean temperature, mean relative humidity, mean wind speed, and net global radiation have changed by + 0.182 oC, -0.73%, -0.0365 m/s, and +0.146 MJ/m2 respectively per decade, while the short wave radiation received has decreased by 0.0037 MJ/m2 per decade. The statistical analysis of the evapotranspiration estimations using selected methods showed that the Penman-Monteith, Blaney-Criddle and Pan evaporation methods give similar estimations (P = 0.05) and are suitable for the study area. When changes to the present climate are imposed for future decades, the over-estimation rate is linear with the Blaney-Criddle and Penman methods whereas for the Penman-Monteith method it is exponential. The overall increment expected after 5 decades is 5.3% and 6.9% with Penman and Blaney-Criddle methods respectively. The Penman-Monteith shows a 74.4% increment in the evapotranspiration over the next five decades.

Keywords: Evapotranspiration, estimation methods, climate change, global warming

INTRODUCTION

The emission of green house gases such as carbon dioxide; radioactively active gases and aerosol precursors modifies the climate and a major concern is temperature increase. The future global warming is predicted to increase by 0.1°C to 0.3°C over a period of a decade (Raper *et al.* 1996). The other climatic parameters that could be affected because of the global warming are rainfall, cloudiness, humidity, windiness and evaporation or evapotranspiration.

As any change in the climate will change the evaporation, evapotranspiration, rainfall and so on, the water budget in any region will be altered and this will have major consequences on agriculture. The climate change will affect water resources and consequently will have an impact on all the agricultural activities.

Chattopadhyay and Hulme (1997) reported that the temperature in southern and central parts of India increased for all the seasons from 1940 – 1990. They analysed evaporation time series data for different parts of India and showed that both pan evaporation and potential evapotranspiration have decreased in recent years. The main reasons behind this were the increased relative humidity and decreased radiation. They also suggested that the increase or change in potential evapotranspiration would be unequal between regions and seasons. Peterson *et al.* (1995) also reported a decrease in potential evapotrans-piration and suggested that the increase in cloudiness and decrease in solar radiation are mostly responsible for this.

Thomas (2000) reported that an average decrease in potential evapotranspiration by 0.21% per year could be attributed to widespread reduction in short wave radiation. Brutsaert and Parlange (1998) suggested that the decrease in relative humidity due to the global climate change has increased the actual evaporation rates. This has led to a decrease in the potential evaporation.

However, Chattopadhyay and Hulme (1997) also found a bigger influence of the energy term in the Penman method (Penman 1948) on potential evapotranspiration change over tropics. As such, the evapotranspiration will increase if the relative humidity decreases and solar radiation increases due to a decrease in cloudiness because of global warming.

Increasing concentrations of greenhouse gases started to increase troposphere temperature. This phenomenon is affecting the cloudiness, humidity and windiness. Received solar radiation could change if cloudiness is affected by greenhouse warming. Humidity and wind speed might also be altered by greenhouse warming, inducing changes in climate. The objective of the study is to check the sensitivity of the evapotranspiration to the climate changes (temperature, solar radiation, relative humidity and wind speed) in the study area to select a proper method for estimating evapotranspiration.

METHODOLOGY

Study Area and Data Collection

The study area, Seberang Perak paddy estate, is located at 40° 7' N and 101° 4' E, and lies 10 km from the west coast of Peninsular Malaysia. Seberang Perak has a tropical climate characterised 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 - 200 mm per month) and October-November (rainfall between 200 - 300 mm per month). The distinct dry seasons are from December to February (150- 175 mm per month) and June to September (less than 150 mm per month).

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 just above 26°C. The maximum temperature of the project area is about 32°C and the minimum is about 23°C, which are more or less uniform throughout the year. Total evaporation starts to increase from December to March/April reaching a maximum (>110 mm per month) and the 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 temperature (maximum, minimum), relative humidity (maximum, minimum), wind speed, solar radiation, sunshine duration, atmospheric pressure, and pan evaporation.

Evapotranspiration Methods and Simulation

The 30 years of daily data of mean temperature, mean relative humidity, wind speed and net global radiation were used to analyse the trends of change in a decade. Eight evapotranspiration estimation methods, the most common and widely used by other researchers for the purpose of evapotranspiration estimation, were tested for their validity for the study area. The eight methods tested in this study were Penman (Penman, 1948), Penman-Monteith (Monteith 1965 and 1981), Pan Evaporation, Kimberly-Penman (Jensen *et al.* 1990), Priestley-Taylor (1972), Hargreaves (Salazar *et al.* 1984), Samani-Hargreaves (Samani and Hargreaves 1985) and Blaney-Criddle (Allen and Pruitt 1986). The details of these methods are given in Appendix I.

The inputs (temperature, solar radiation, wind speed and relative humidity) were changed individually in all the methods between ±30% with a step variation of ±10%. All the inputs were varied as a percentage of daily historical values. When monthly average values were needed for Blaney-Criddle, Hargreaves and Samani Hargreaves the daily-varied values were used in the calculation of the monthly average values of the required inputs. The climatic trends found in this study were next applied to forecast possible future trends in evapotranspiration.

RESULTS AND DISCUSSION

The analysis shows that the mean temperature has increased by 0.182°C per decade during the last 30 years. The mean relative humidity has dropped by 0.73% per decade. The mean wind speed has dropped by 0.0365 m/s per decade. The net global radiation has increased by 0.146 MJ/m^2 but the net incoming short wave radiation has decreased by 0.0037 MJ/m^2. Nicholls *et al.* (1996) reported that the earth surface temperature has increased since the 1850s by about 0.5°C or about 0.04°C per decade. Raper *et al.* (1996) estimated that the future global warming would modify the atmospheric temperature between 0.1 °C and 0.3 °C per decade. This study in the west coast of Peninsular Malaysia on the temperature increase trend shows agreement with those estimated by Raper *et al.* (1996). This study shows an increasing trend in pan evaporation that is attributed to the changes in climatic parameters, especially with the increase in temperature and decrease in relative humidity, similar to what Cohen *et al.* (2002) showed at Bet Dagan.

The monthly averages of the evapotranspiration estimates by all the eight methods were tested with a Randomised Complete Block Design where a mean separation procedure was done to verify the differences between different methods of estimations. The results of a two-way ANOVA are given in Table 1.

TABLE 1
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 $P = 0.05$

The methods of Blaney-Criddle, Pan and Penman-Monteith give the lowest values and there are no significant differences among them ($P = 0.05$). All other five methods are significantly different from the Blaney-Criddle, Pan and Penman-Monteith methods. The estimates of Penman, Kimberly Penman and Priestley-Taylor methods significantly differ from each other. The methods of Hargreaves and Samani-Hargreaves give the highest values. These two methods do not have any significant differences between them (P=0.05). Thus, the methods of Blaney-Criddle, Pan and Penman-Monteith are suitable for the study area in the west coast of Peninsular Malaysia. However, the Penman-Monteith has universal acceptance (Allen *et al.* 1998).

Fig. 1 shows the percentage change in reference evapotranspiration to a percentage change in temperature. All the eight methods show a corresponding linear trend of increase/decrease of evapotranspiration with a temperature increase/decrease. The three temperature-based methods of Hargreaves (H in *Fig. 1*), Samani-Hargreaves (SH) and Blaney-Criddle (BC) are most sensitive to temperature change, with Hargreaves showing the highest trend while Blaney-Criddle the lowest. The Pan method (Pan) does not have any variable in terms of temperature. The Kimberly-Penman (KP) method shows the lowest variation with temperature change. All the combination methods used in this study, Kimberly-Penman, Penman (P), Penman-Monteith (PM) and Priestley-Taylor (PT) methods, respond in a similar way and the variation of evapotranspiration is more or less the same. Out of the four methods suitable for the project area, the Penman-Monteith gives 8.8% and 28.7% change in evapotranspiration for a change of +10% and +30% in temperature respectively, whereas the Blaney-Criddle shows a 9.0% and 27.0% while Penman shows 8.0% and 26.1% for similar changes.

Six methods have relative humidity as an input either directly or indirectly. Blaney-Criddle, Kimberly-Penman and Penman methods show a linear trend (*Fig. 2*). Evapotranspiration decreases with an increase in relative humidity when Blaney-Criddle, Kimberly-Penman and Penman methods are applied. Blaney-Criddle shows the largest change in evapotranspiration (-28.1% change in evapotranspiration for a +30% increment in relative humidity). Kimberly-Penman and Penman methods show -15.6% and -9.4% changes in evapotranspiration respectively for a +30% increase in relative humidity. Pan, Penman-Monteith and Priestley-Taylor show linear relationships where an increase in relative humidity increases the evapotranspiration.

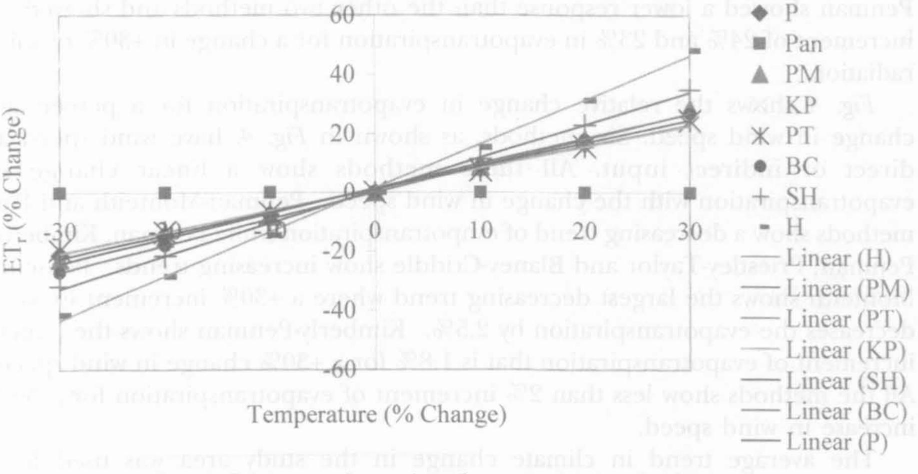

Fig. 1: Percentage change in reference evapotranspiration to a percentage change in temperature at Seberang Perak

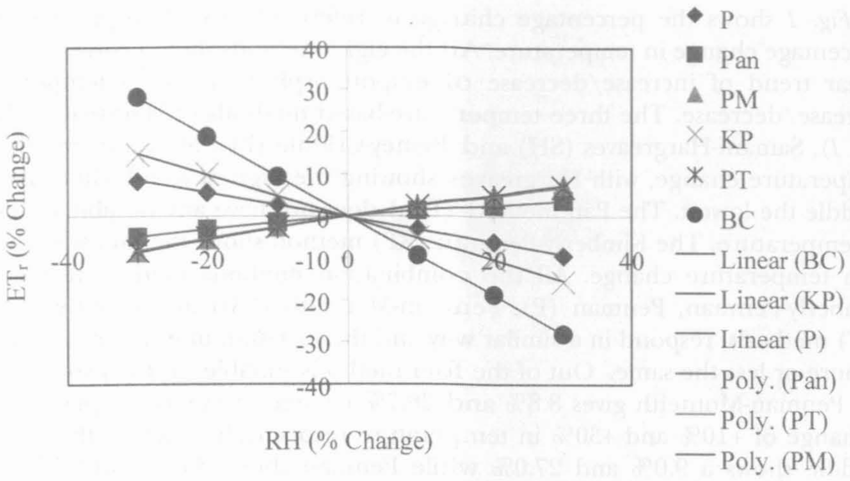

Fig. 2: Percentage change in reference evapotranspiration to a percentage change in relative humidity at Seberang Perak

Solar radiation received at a location varies with the change in cloudiness due to global warming. Out of eight methods tested in this study, all combination methods (Penman, Penman-Monteith, Kimberly-Penman, and Priestley-Taylor) use solar radiation as an input. All four methods show a linear trend in evapotranspiration estimates with a percentage change in solar radiation (*Fig. 3*). With the Penman-Monteith and Priestley-Taylor, a +30% increment in solar radiation results in estimating 26.5% more evapotranspiration. Penman-Monteith did not response more than 20% when solar radiation is incremented by +30% in the study by McKenney and Rosenberg (1993). Penman and Kimberley-Penman showed a lower response than the other two methods and showed an increment of 24% and 23% in evapotranspiration for a change in +30% of solar radiation.

Fig. 4 shows the relative change in evapotranspiration for a percentage change in wind speed. Six methods, as shown in *Fig. 4*, have wind speed as direct or indirect input. All these methods show a linear change in evapotranspiration with the change in wind speed. Penman-Monteith and Pan methods show a decreasing trend of evapotranspiration while Penman, Kimberly-Penman, Priestley-Taylor and Blaney-Criddle show increasing trends. Penman-Monteith shows the largest decreasing trend where a +30% increment in wind decreases the evapotranspiration by 2.5%. Kimberly-Penman shows the largest increment of evapotranspiration that is 1.8% for a +30% change in wind speed. All the methods show less than 2% increment of evapotranspiration for a 30% increase in wind speed.

The average trend in climate change in the study area was used in a simulation to evaluate the future trends in evapotranspiration estimation by the three methods (Penman-Monteith, Penman and Blaney-Criddle) that gave non-significant differences. The pan evaporation will vary with the temperature

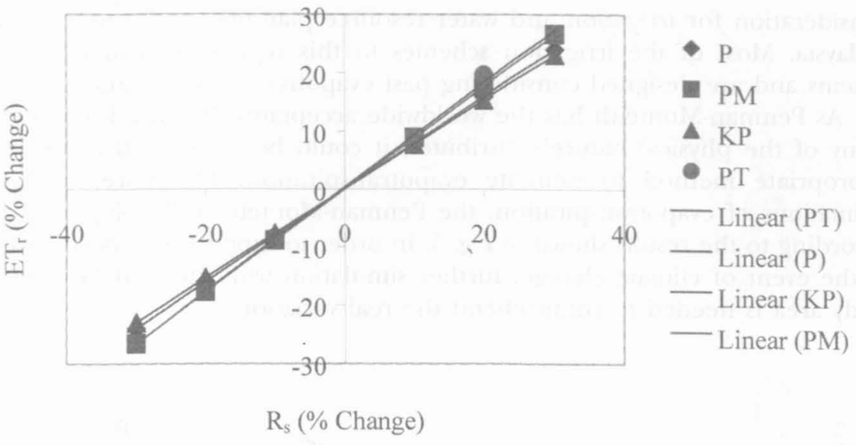

Fig. 3: Percentage change in reference evapotranspiration to a percentage change in net global radiation at Seberang Perak

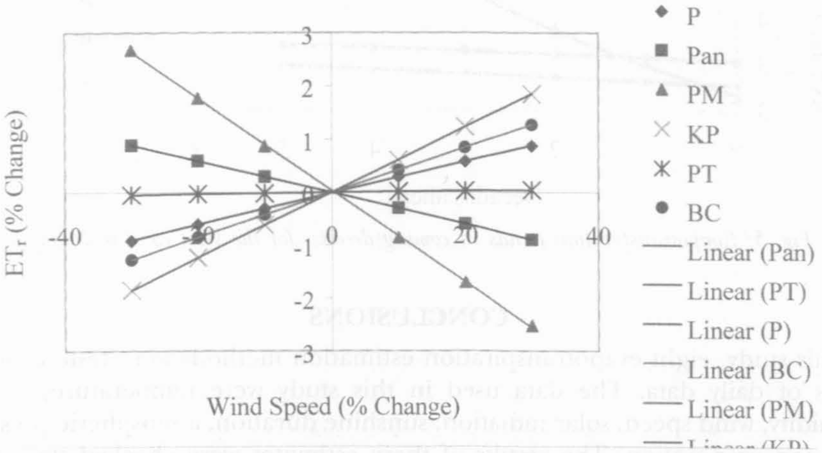

Fig. 4: Percentage change in reference evapotranspiration to a percentage change in wind speed at Seberang Perak

change but the available values for the past three decades cannot be used in the future estimations. The results are shown in *Fig. 5* and all three methods show an increasing trend in evapotranspiration. Blaney-Criddle and Penman methods show a linear increment while the Penman-Monteith shows an exponential trend. The Blanney-Criddle method however gave higher estimates when compared to the Penman method. The overall increment expected after 5 decades is 5.3% and 6.9% with the Penman and Blaney-Criddle methods respectively. The Penman-Monetith shows a 74.4% increment in the evapotranspiration in the next five decades. Penman-Monteith shows the same exponential trend when average monthly evapotranspiration for each month is considered. The increasing trend of evapotranspiration has to be taken into consideration for irrigation and water resource planning in the west coast of Malaysia. Most of the irrigation schemes in this region are run-of-the river systems and are designed considering past evapotranspiration data.

As Penman-Monteith has the worldwide acceptance because it encumbers many of the physical nature's attributes, it could be considered as the most appropriate method to estimate evapotranspiration. Therefore, in future estimations of evapotranspiration, the Penman-Monteith will only be suitable according to the results shown in *Fig. 5*. In order to support the above findings in the event of climate change, further simulation with future data from the study area is needed to comprehend the real variations.

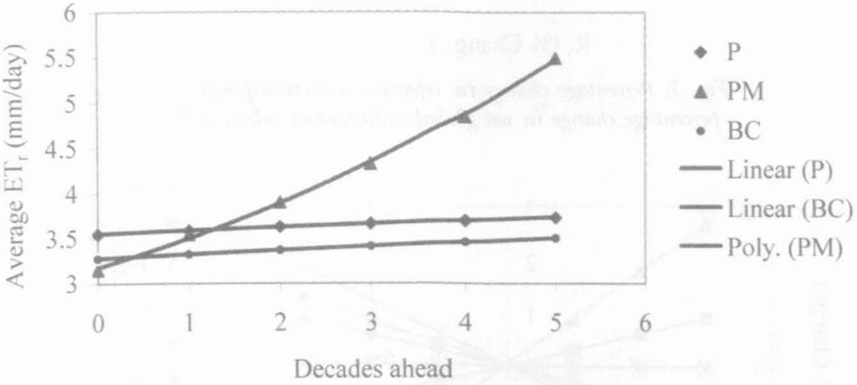

Fig. 5: Evapotranspiration trends in coming decades for the West coast of Malaysia

CONCLUSIONS

In this study, eight evapotranspiration estimation methods 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 results of these estimates were checked statistically and it was found that 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 were significantly different from these three methods. The analysis of the last 30 years data showed that the mean temperature has increased by 0.182°C per decade. The mean relative humidity has dropped by 0.73% per decade. The mean wind speed has dropped by 0.0365 m/s per decade. The net global radiation has increased by 0.146 MJ/m^2 but the net incoming short wave radiation has decreased by 0.0037 MJ/m^2.

All the eight methods show a linear trend of increase or decrease of evapotranspiration with corresponding temperature increase or decrease. The three temperature-based methods of Hargreaves, Samani-Hargreaves and Blaney-Criddle are most sensitive to temperature change. Evapotranspiration decreases with an increase in relative humidity with the Blaney-Criddle, Kimberly-Penman and Penman methods. The Penman-Monteith and Priestley-Taylor methods show the highest effect on evapotranspiration where a +30% increment in solar radiation results in 26.5% more evapotranspiration. Penman-Monteith shows the largest decreasing trend where a +30% increment in wind decreases the evapotranspiration by 2.5%. Logically, when wind speed increases, evaporation should follow suit. Thus there could be a limitation as to the values of physical parameters that can be input into the Penman-Monteith equation and in fact into all the other equations. In other words there will be limitations to the applications of these equations, which should not be alarming.

When the present trend in climate change (based on historical data) is imposed for future decades, the Blaney-Criddle and Penman methods show a linear increment while the Penman-Monteith indicates an exponential behaviour. The overall increment expected after 5 decades is 5.3% and 6.9% with Penman and Blaney-Criddle methods respectively. The Penman-Monteith shows a 74.4% increment in the evapotranspiration in the next five decades. Penman-Monteith shows the same exponential trend when average monthly evapotranspiration for each month is considered. Since it is the FAO recommended method, serious concerns will have to be placed on future water management to avoid being caught unprepared.

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Appendix I: Evapotranspiration methods used in this study

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

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), ρ_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, γ 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 extraterrestrial radiation (mm/day), ∂T_f is the difference between mean monthly maximum and mean monthly minimum temperatures (°F), Tf 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.