A Simple Regression Model for Estimating Actual Evapotranspiration in Various Types of Land Use, THAILAND

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Abstract

The actual evapotranspiration (AET) of paddy field (PDF), mixed deciduous forest with dry dipterocarp (MDF) and teak plantation (TPT) in the northern Thailand based on Bowen ratio method was studied during June 1997 to May 2015. The results found that in PDF the yearly average AET were 3.3 mm day^{-1} while pan evaporation (E_{pan}) was 4.9 mm day^{-1}. In MDF and TPT, the yearly average AET were 3.7 and 3.6 mm day^{-1} while E_{pan} were 5.5 and 3.3 mm day^{-1} respectively. The simple regression model for estimating AET was developed by using climatic data as independent variable such as air temperature (T_a), wind speed (WS), soil moisture tension (pF) and relative humidity (RH). The suitable models were selected by all possible regression method. Only significantly and logically simple models for estimate daily AET in difference period in each land use

Keywords: regression model, actual evapotranspiration, land use

1. Introduction

Evapotranspiration (ET) represents the water loss from watershed and is a key component of the hydrological cycle. But the difficult in determining actual evapotranspiration (AET) by Bowen ratio and energy balance method which the data must be measured at difference 2 levels above plant canopy continuously with the expensive in instrument setting up. Since 1997, the AET by Bowen ratio and energy balance method was studied in various kind of land use in northern Thailand under the GAME-T and CEOP project. Therefore, a simple model for estimating AET should be developed by using ordinary climatic data. The objectives of this study are to find out the significant simple regression model for estimating AET in each land use type and to verify the model.

2. Materials and Methods

2.1 Measurement site

As three typical land use type in northern Thailand, a rain fed paddy field (PDF), mixed deciduous with dry dipterocarp forest (MDF) in Sukothai province and teak plantation (TPT) in Lampang province were selected. The detail of each study site is shown in Table 1.

2.2 The equipment installation

The Automatic Weather Station (AWS) was installed. Temperatures wet and dry bulb thermometer at two height levels above plant canopy, wind velocity, net radiation, soil heat flux by 3 sets of soil heat flux plate and soil temperature by the mister were measured at different heights detail in Table 1.

2.3 Data collection and transmission

Average 10 minute of all data in each site was collected in 30 channel data logger. Data from the data logger were transmitted through modern and mobile phone only in the PDF and TPT but in MFD the data was transmitted by personal computer at the site.

Table 1: Location and sensor position of each study site

Location and instrument	Measurement sites		
	PDF	MDF	TPT
1. Location in topographic map			
1.1 Topographic map sheet number of Thailand	4943 III	4943 III	4945 III
1.2 Latitude (N)	17°04′16″	17°01′38″	18°25′16″
1.3 Longitude (E)	99°42′18″	99°36′57″	99°43′28″
2. Elevation (m. MSL)	50	79	380
3. Average vegetation height (m)	1.5	5	14
4. Sensor's position (above ground in m.)			
4.1 Anemometer (WS, WD)	11	12	25
4.2 Upper thermometer (T_a, T_w, RH)	9.5	10.9	24
4.3 Infrared thermometer (IRT)	10	10.5	24.5
4.4 Pyreliometer and net radiometer (R_s and R_n)	7.5	6.7	21.8
4.5 Lower psychometer (T_a, T_w, RH)	2	5.9	17
5. Sensor's position (depth in soil in cm.)			
5.1 Soil temperature (T_s)	1, 15	1, 15	1, 15
5.2 Soil heat flux meter (G_s)	1	1	1
5.3 Tensiometer (pF)	15	15	15

2.4 Data analysis

The software program was developed by Aoki *et al* (1997) to convert the data into text file data as daily data. Then diurnal heat balance and evapotranspiration were calculated. The actual evapotranspiration by energy balance and Bowen ratio method can be simplified as follow:-

$$R_n = H + G_s + G_w + LE \qquad (1)$$

$$B = H / LE = (C_p{*}P / 0.622L)\,(\Delta T / \Delta e) \qquad (2)$$

$$AET = (R_n - G_s - G_w) / L(1 + B) \qquad (3)$$

$$L = 2500.8 - 2.3668\, T_a \qquad (4)$$

Where,

R_n = net radiation (MJ m^{-2})
H = sensible heat flux (MJ m^{--2})
G_s = soil heat flux (MJ m^{-2})
LE = latent heat flux (MJ m^{-2})
G_w = heat storage in water (MJ m^{-2})
B = Bowen ratio
C_p = specific heat of air (J ^oC g^{-1})
P = air pressure (mb)
AET = actual evapotraspiration (mm day^{-1})
T_a = average daily air temperature (^0C)
ΔT = difference between the lower and the upper air temperatures (^0C)
Δe = difference between the lower and the upper vapor pressure (mb)

3. Result and Discussion

3.1 Actual evapotranspiration (AET)

The result of measured climatic data and calculated AET in each land use type were shown in Table 2. The average AET is the highest (3.7 mm day^{-1}) in MDF and almost the same amount in TPT (3.6 mm day^{-1}). While average AET at PDF is the lowest (3.3 mm day^{-1}). Because of largest amount of average R_n in MDF (R_n = 14.3 MJ m^{-2} day^{-1}) While average R_n in TPT and PDF were 10.8 and 12.1 MJ m^{-2} day^{-1} respectively.

3.2 A simple model for estimating daily AET

In order to establish the monthly model for estimate the daily AET, the meteorological factors such as air temperature (T_a), wind speed (WS), soil moisture tension (pF), relative humidity (RH) were employed. Therefore a simple regression model for estimating daily AET should be developed for each land use type.

The models were selected by all possible regression method. Only significant model was shown in table 3 and can be described in each site as follows:

3.2.1 Paddy field in Sukhothai province (PDF)

1) Daily AET estimating model for each month

In general, the increasing of T_a (positive value) and the decreasing of RH (negative value) would increase the daily AET. On the contrary, when the PDF was very dry especially T_a in January and RH in February and March would have reverse effect to the daily AET (table 3). This could be explained that in case of enough moisture for AET; On the other hand, when the PDF was very dry, the decreasing T_a and increasing RH would make higher air moisture and also higher daily AET. So, if we would like to apply these models, it must be considered not only a high R^2 but also logical expression of all parameters in equation.

2) Daily AET estimating model for rice planting season and out of planting season

Due to the different of activities in paddy field between during rice planting season and out of season rice planting. Therefore, the estimating daily AET in each period should be study. Hence, the significant model of each season was shown as below and can be explained as following:

Table 2: Average meteorological conditions and AET in various type of land use where the measurement were carried out in northern Thailand

Land use	E_{pan} (mm day^{-1})	AET (mm day^{-1})	Average meteorological data			
			T_a (°C)	pF	WS (m s^{-1})	RH (%)
1. Paddy field, Muang, Sukhothai province (PDF) Yearly average	4.9	3.3	29.9	2.5	2.5	69.0
2. Mixed deciduous forest with dipterocarp (MDF), Bandanlanhoi, Sukhothai province Whole period	5.5	3.7	31.7	2.3	1.7	59.8
3. Teak plantation, Mae Moh, Lampang province (TPT) Whole period	3.3	3.6	26.6	2.0	1.4	74.1

Table 3: Daily AET estimating model for each month at PDF in Sukhothai province.

Month	Model	Statistical parameters		
		R^2	F-ratio	SEE
June	$AET_{JUN} = -5.2 + 0.205T_a$	0.79	25.970**	0.20
	$AET_{JUN} = -7.0 + 0.327\ T_a - 0.185VC$	0.93	38.820**	013
July	$AET_{JUL} = 3.1 + 0.244\ T_a - 0.079RH$	0.70	9.176**	0.78
August	$AET_{AUG} = -25.4 + 1.033T_a$	0.88	110.953**	0.55
September	$AET_{SEP} = -3.7 + 0.506\ T_a + 0.001WL + 0.406WS + 0.089RH$	0.80	32.419**	0.51
October	$AET_{OCT} = -\ 3.5 + 0.430\ T_a - 0.059RH$	0.79	66.834**	0.44
November	$AET = 2.3 + 0.165\ T_a - 0.117pF – 0.055RH$	0.55	13.142**	0.58
December	$AET_{NOV} = 1.1 + 0.142\ T_a - 0.045RH$	0.86	24.887**	0.18
January	$AET_{JAN} = 20.2 - 0.605\ T_a - 0.833WS$	0.64	9.652**	0.63
	$AET_{JAN} = 10.7 - 0.333\ T_a - 0.816WS + 0.033VC$	0.72	8.542**	0.58
February	$AET_{FEB} = -3.9 + 0.091RH$	0.93	91.721**	0.38
March	$AET_{MAR} = -\ 32.1 + 0.994\ T_a + 0.045RH$	0.92	48.818**	0.19
April	$AET_{APR} = -8.6 + 0.389\ T_a - 0.225WS$	0.91	45.022**	0.25
May	$AET_{MAY} = -\ 11.0 + 0.531\ T_a$	0.93	71.438**	0.42

Remark: T_a = air temperature (°C), WS = wind speed (m s^{-1}), WL = water level (cm), VC = vegetative cover (%),RH = relative humidity (%), SEE = standard estimate error, ** = significant at 99% confidence interval, AET = actual evapotranspiration (mm day^{-1})

(1) Rice planting season (July – November)

The season usually starts from the middle of July to the middle of November. The average AET was 4.5 mm day^{-1} while the average E_{pan} was 4.3 mm day^{-1} with the averaged AET/E_{pan} of 1.1. The suitable models for estimating AET at PDF in this season are :

$AET_{RPS} = -9.5 + 0.534T_a - 0.020RH$
(R^2 = 0.85, SEE = 0.43) (5)

When vegetative cover (%VC) was considered, the equation has high R^2 as:

$AET_{RPS} = -10.7 + 0.567T_a - 0.025RH + 0.008VC$
(R^2 = 0.90, SEE = 0.36) (6)

(2) Out of planting season (December – June)

The average AET after rice harvesting was 1.9 mm day^{-1} while the average E_{pan} was 4.5 mm day^{-1} with the AET/E_{pan} of 0.4. The suitable models for estimating AET at PDF in this season are:

$AET_{ORS} = 3.8+0.283T_a–3.766pF-0.009RH$
(R^2 = 0.90, SEE = 0.26) (7)

When VC was considered, the VC could not make much different in R^2 as:

$AET_{ORS} = 0.9 + 0.288T_a - 2.745pF + 0.004RH + 0.009VC$
(R^2 = 0.91, SEE = 0.26) (8)

3) Daily AET estimating models derived from all recorded data throughout the year

When the whole data recorded throughout the year were used in model derivation for estimating daily AET for PDF in Sukhothai province, the significant prediction model were shown. It could be said that, the T_a and RH had high effect on AET. The %VC showed insignificant influence on AET with rather low R^2. The suitable model for estimating daily AET was:

$AET_{ANN} = -18.2 + 0.777T_a + 0.002RH$
(R^2 = 0.75, SEE = 0.63) (9)

From above model, the models derived from all observed data throughout the year are not so good for daily AET estimating due to the R^2 was lower than the others models and seem not to be reasonable in logic (positive RH).

3.2.2 mixed deciduous forest with dry dipterocarp (MDF)

The model was formulated to estimate the daily AET in each particular period and annually. The suitable models were selected by all possible regression and statistical parameters (R^2 and F-ratio). Only the significant models were shown and can be explained as follows:

1) Prediction model for HW period

HW period (High temperature and high rainfall amount) is a period when the monthly air temperature and monthly rainfall amount were higher than the annual average. For Sukhothai province, it was in May until October or 6 months in total, T_a and WS don't have significant effect on AET as well as pF and RH. The effect of soil moisture and humidity under the canopy seem to be that more than of T_a and WS over the canopy. The suitable models for estimating daily AET are given below:

$AET_{WPF} = 22.9 - 4.469pF - 0.133RH$
(R^2 = 0.94, SEE = 0.51) (10)

The R^2 of the model was so high and significant at 99% confidence interval. When the factors Rain and VC were added in the model, The R^2 was a little increased.

2) Prediction model for HD period

HD period (High temperature and low rainfall amount) is a period when the monthly air temperature in that month was higher than annual average but rainfall amount was lower than annual average. For Sukhothai province, it was in March and April or 2 months in total. From the study, no significant model for estimating daily AET was selected statistical analysis.

3) Prediction model using all data collected throughout the year

The model was formulated by using all data collected throughout the year which 2/3 of data come from HW period. The most suitable equations are as follows:
$AET_{ANF} = -1.5 + 0.499T_a - 4.575pF$

(R^2 = 0.77, SEE = 0.86) (6)

3.2.3 Teak plantation (TPT)

The model formulating for estimate the daily AET for each particular period and for annual data basis at teak plantation implied the significant influence of the meteorological factors such as T_a, WS, RH and pF. The suitable models were selected by all possible regression. Only the significant models were shown below and can be concluded as follows:

1) HW period prediction models

HW period (High temperature and high rainfall amount) is a period when the monthly air temperature and monthly rainfall amount were higher than the annual average. For Lampang province, it was in April until September or 6 months in total, The suitable equations for estimating daily AET are as follows:

$AEt_{WPT} = -8.9 + 0.548T_a - 0.958pF$
(R^2 = 0.88, SEE = 0.48) (12)

When the VC was considered, the equation becomes:

$AEt_{WPT} = -5.1 + 0.893(-8.9+0.548T_a-0.958pF) + 0.066VC$
(R^2 = 0.94, SEE = 0.34) (13)

2) LD period prediction model

LD period (Low temperature and low rainfall amount) : a period when the monthly air temperature and rainfall amount in that month were lower than annual average. For Lampang province, it was in November until February or 4 months in total. From this study, no significant model for estimating daily AET was selected using statistical analysis as R^2 and F-ratio.

3) Prediction model using all data throughout the year

In case of using only climatic factors, there is insignificant model for estimate AET. When pF was added, the significant model was showed as equation below:

$AEt_{ANT} = -7.2 + 0.481T_a - 0.939pF$
(R^2 = 0.80, SEE = 0.52) (14)

3.3 Model verification

The model verification were presented by the relationship between modeled AET (AET_{est}) and measured AET (AET_{mea}) which shown in figure 1 to figure 4 for every month at PDF, rice planting at PDF, MDF and TPT respectively. It can be described as follow:

3.3.1 Daily AET estimating model for each month at PDF

Figure 1 shows that the correlation coefficient (r) in each month was so high. The lowest r was only 0.74 in November. These seem that the models in table 3 are well for apply. The R^2 in some model was so high but it's not reasonable in logic especially in September and January to March.

3.3.2 Daily AET estimating for rice planting season and throughout the year at PDF

The correlation coefficient (r) of relationship between AET_{est} and AET_{mea} in rice planting season, out season rice planting and throughout the year was 0.92, 0.95 and 0.87 respectively (figure 2). But the model for estimate AET for throughout the year is not suitable to applied because the logical expression.

3.3.3 Daily AET predicting model for each period at MDF

The relationship between AET_{est} and AET_{mea} which shown by r-value in figure 3 was 0.97 and 0.89 for wet period (HW period) and throughout the year respectively.

3.3.4 Daily AET predicting model for each period at TPT

As same as at MDF, The relationship between AET_{est} and AET_{mea} which shown by r-value At TPT in figure 4 was 0.94 and 0.89 for wet period (HW period) and throughout the year respectively.

4. Conclusion

A simple model for estimating the daily AET was developed by using the climatic data such as T_a, WS, pF, RH including %VC for each land use type in northern Thailand. The suitable models were selected by all possible regression method. Only significantly and logically models were suggested as follows:

at PDF : for rice planting season

$AET_{RPS} = -9.5 + 0.534T_a - 0.020RH$
($R^2 = 0.85$, SEE = 0.43)

at PDF : for out of planting season

$AET_{ORS} = 3.8 + 0.283T_a – 3.766pF - 0.009RH$
($R^2 = 0.90$, SEE = 0.26)

at MDF : for throughout the year

$AET_{ANF} = -1.5 + 0.499T_a - 4.575pF$
($R^2 = 0.77$, SEE = 0.86)

at TPT : for throughout the year

$AEt_{ANT} = -7.2 + 0.481T_a - 0.939pF$
($R^2 = 0.80$, SEE = 0.52)

However, due to the continuous measurement in paddy field started since 1997 while at MDF and TPT only periodical measurement was observed. Therefore, it's needs to continue measurement and need more data in each land use type for more accuracy in model formulation.

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