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ESTIMATING POTENTIAL EVAPOTRANSPIRATION

Tohari

INTISARI

Penelitian dilaksanakan untuk menguji kemampuan empat model estimasi evapotranspirasi potensial dan menentukan faktor pengendali evapotranspirasi potensial.

Hasil penelitian menunjukkan bahwa persamaan Penman yang dimodifikasi, persamaan Penman yang disederhanakan, evaporasi pan yang disesuaikan dan evaporasi pan mempunyai kemampuan yang setara dalam penaksiran evapotranspirasi potensial. Faktor pengendali evapotranspirasi potensial adalah nisbah penyinaran matahari aktual terhadap panjang hari, suhu udara rata-rata, kecepatan angin pada ketinggian 2 m di atas permukaan tanah dan kelembaban relatif udara. Berdasarkan hasil penelitian disarankan bahwa data evaporasi pan dapat digunakan sebagai evapotranspirasi potensial taksiran karena prosedurnya sangat sederhana.

ABSTRACT

The experiment was conducted to evaluate four estimation models of potential evapotranspiration and decide the determinant factor(s) of potential evapotranspiration.

The results showed that modified Penman formula, simplified Penman formula, an adjusted pan evaporation and pan evaporation had comparable ability in estimating potential evapotranspiration. The bright sunshine to length of day ratio, mean air temperature, and windspeed at 2 m above the ground are the main constituent of driving forces of potential evapotranspiration.

On the basis of the overall results it is clear that the pan evaporation should be recommended to be used as the estimate of potential evapotranspiration, since need only the simplest procedure.

INTRODUCTION

The amount of water that evaporates from the soil or water surface in the case of wetland rice and that transpires from the leaf area depend on the soil moisture conditions on one hand and the development stage of the crop on the other hand. Therefore, potential evapotranspiration was introduced by Penman (1948) which defined as the maximum quantity of water which may be evaporated by a uniform cover of dense and short grass when water supply to the soil is not limited. Doorenbos and Pruitt (1977) have summarized various methods to compute potential evapotranspiration, depending on the quantity and quality of measured climatic variables.

The Blaney-Criddle method is used to compute the potential evapotranspiration if air temperature data are only available. It is

$$PET_i = c\,[\,p(0.46\,T_i + 8)\,] \qquad (1)$$

where:

PET_i = potential evapotranspiration in mm/day

T_i = mean daily temperature in ^oC

p = mean daily percentage of total annual daytime hours for a given month and latitude

c = adjusted factor which depends on minimum relative humidity, sunshine hours and daytime wind estimates

Potential evapotranspiration can also be computed using the Radiation method (Makkink, 1957) if air temperature, sunshine and cloudiness or radiation data are available, it is

$$PET_i = c\,(W.Rs) \qquad (2)$$

where:

PET_i = potential evapotranspiration in mm/day

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Rs = solar radiation in equivalent evaporation in mm/day

W = weighting factor which depends on temperature and latitude

c = adjustment factor which depends on mean humidity and daytime wind conditions

While the Penman method is used instead if the measured data on temperature, relative humidity, wind speed and sunshine duration (or radiation) are available. The equation is

$$PET_i = c\,[W.Rn + (1-W).f(u)(e_a-e_d)] \quad (3)$$

where:

PET_i = potential evapotranspiration in mm/day

W = temperature related weighting factor

Rn = net radiation in equivalent evaporation in mm/day

f(u) = wind related function

(e_a-e_d) = difference between the saturation vapor pressure at mean air temperature and the mean actual vapor pressure of the air, both in mbar

c = adjustment factor to compensate for the effect of day and night weather conditions.

In estimating potential evapotranspiration, Tamisin (1977) modified the original Penman formula for the Philippines condition, as follows:

1. The value of reflection coefficient of the surface (r) used was 0.25 to represent a normally growing green vegetation cover,
2. The term $(0.5 + 0.01\ U_2)$ in the expression of the aerodynamic term $Ea = 0.27\ (0.5 + 0.01\ U_2)\ (e_a - e_d)$ was replaced by $(1.0 + 0.01\ U_2)$ to carry an allowance for roughness factor,
3. The term $(0.56 - 0.09\sqrt{e_d})$ in the energy balance equation $Rn = (1\text{-}r)Rt - s(T_a)^4(0.56 - 0.09\sqrt{e_d})\ (0.10 + 0.90\ n/N)$ was replaced by$(0.56 - 0.079\sqrt{ed})$ to be applicable to generally humid areas. In the simple form, the Penman equation is

$$PET_i = \frac{\Delta\,Rn + \gamma\,Ea}{\Delta + \gamma} \qquad (4)$$

where:

Δ = slope of saturation vapor pressure curve for water at mean air temperature in mmHg/°C. The values are given in Table 1.

Rn = an estimate of net radiation in equivalent evaporation in mm/day

$Rn = (1\text{-}r)Rt - s(Ta)4(0.56 - 0.079\sqrt{e_d})\ (0.10 + 0.90\ n/N)$

r = reflection coefficient of surface (0.25)

Rt = global radiation in cal/cm2/day

$s(T_a)^4$ = longwave losses from the earth's surface radiation, the values are given in Table 2.

e_d = actual vapor pressure of the air in mbar

n/N = ratio actual/possible hours of sunshine

γ = standard psychrometric constant (0.27)

Ea = evaporation in mm/day

$Ea = 0.27\ (1.0 + 0.01\ U2)(e_a-e_d)$

U_2 = wind speed at 2 meters height in km/day

e_a = saturation vapor pressure, mean of values obtained at daily maximum and daily minimum temperatures in mbar (Table 2)

Table 1. Δ (slope of saturation vapor pressure) as function of Ta (mmHg)

Ta (°C)	0	0.2	0.4	0.6	0.8
10	0.3325	0.3360	0.3396	0.3431	0.3467
11	0.3502	0.3542	0.3582	0.3622	0.3662
12	0.3702	0.3746	0.3790	0.3835	0.3879
13	0.3923	0.3971	0.4019	0.4067	0.4115
14	0.4163	0.4216	0.4269	0.4322	0.4375
15	0.4428	0.4447	0.4518	0.4563	0.4608
16	0.4705	0.4760	0.4815	0.4870	0.4924
17	0.4969	0.5034	0.5088	0.5143	0.5198
18	0.5254	0.5309	0.5364	0.5418	0.5413
19	0.5530	0.5584	0.5639	0.5694	0.5784
20	0.5805	0.5860	0.5914	0.5969	0.6024
21	0.6145	0.6200	0.6255	0.6309	0.6369
22	0.6485	0.6553	0.6621	0.6689	0.6757
23	0.6826	0.6894	0.6962	0.7030	0.7098
24	0.7166	0.7336	0.7304	0.7373	0.7414
25	0.7506	0.7574	0.7642	0.7710	0.7778
26	0.7933	0.8001	0.8069	0.8137	0.8205
27	0.8359	0.8444	0.8530	0.8615	0.8700
28	0.8786	0.8871	0.8956	0.9042	0.9127
29	0.9212	0.9298	0.9383	0.9468	0.9554
30	0.9639	0.9743	0.9846	0.9950	1.0054
31	1.0157	1.0261	1.0365	1.0469	1.0572
32	1.0676	1.0780	1.0883	1.0987	1.1091
33	1.1194	1.1298	1.1402	1.1505	1.1609

Table 2. $s(T_a)^4$ (Boltzman constant) for various mean air temperature (Ta) and saturation vapor pressure (e_a in mbar) as a function of mean air temperature (T_a in ^oC)

^oC	$s(T_a)^4$			e_a				
	Ta	0.0	0.5	0.0	0.2	0.4	0.6	0.8
10	283	12.8	12.9	12.3	12.4	12.6	12.8	13.0
11	284	13.0	13.1	13.2	13.3	13.5	13.7	13.8
12	285	13.2	13.3	14.0	14.2	14.4	14.6	14.8
13	286	13.4	13.5	15.0	15.2	15.4	15.6	15.8
14	287	13.6	13.7	16.0	16.2	16.4	16.6	16.8
15	288	13.8	13.9	17.0	17.2	17.5	17.7	17.9
16	289	14.0	14.1	18.2	18.4	18.7	18.9	19.2
17	290	14.3	14.4	19.4	19.6	19.8	20.1	20.3
18	291	14.5	14.6	20.6	20.9	21.2	21.4	21.7
19	292	14.7	14.8	22.0	22.3	22.6	22.8	23.1
20	293	14.9	15.0	23.4	23.7	24.0	24.3	24.6
21	294	15.1	15.2	24.9	25.2	25.5	25.8	26.1
22	295	15.3	15.4	26.4	26.7	27.1	27.4	27.7
23	296	15.5	15.6	28.1	28.4	28.7	29.1	29.4
24	297	15.7	15.8	29.8	30.2	30.6	30.9	31.3
25	298	15.9	16.0	31.7	32.1	32.5	32.8	33.3
26	299	16.1	16.2	33.6	34.0	34.4	34.9	35.3
27	300	16.3	16.4	35.7	36.1	36.5	37.0	37.4
28	301	16.5	16.6	37.5	38.2	38.6	39.1	39.5
29	302	16.7	16.8	40.1	40.6	41.0	41.5	41.9
30	303	17.0	17.1	42.4	42.9	43.3	43.8	44.2
31	304	17.2	17.3	44.9	45.4	45.9	46.4	46.9
32	305	17.4	15.5	47.5	48.1	48.7	49.2	49.8
33	306	17.6	17.7	50.2	50.8	51.4	51.9	52.5

In cases where:

1. The value of global radiation (Rt), if not available, was replaced by Ro(a + b n/N) when sunshine duration n/N data is available.
2. Constant "a" and "b" has been derived for different regions in the Philippines. The value of a and b for UPLB College Laguna were 0.24 and 0.53, respectively. The value of Ro for each month of the year for UPLB College Laguna (at 15° North Latitude) are given in Table 3.
3. When only data on relative humidity (RH) are available, the value of actual vapor pressure of the air (e_d) was computed as e_d = RH/100 x e_a, in which e_a is the saturation vapor pressure at daily mean temperature.

The values of potential evapotranspiration are usually not available, and sometime required in the study of water related problems such as irrigation (Doorenbos and Pruitt, 1977), soil and crop water relation (Slatyer, 1967), the dynamic of soil moisture content (Baier and Robertson; 1966; Frere and Popov, 1979; Mota, 1983) and estimating actual evapotranspiration (Baier and Robertson; 1966; Mota, 1983). It has, therefore, to be estimated.

Table 3. Extra-terrestrial radiation Ro (equivalent evaporation in mm/day)

Months	Extra-terrestrial radiation Ro	Months	Extra-terrestrial radiation Ro
January	12.2	July	15.8
February	13.4	August	15.7
March	14.8	September	15.1
April	15.7	October	14.0
May	15.9	November	12.6
June	15.8	December	11.8

MATERIALS AND METHODS

Four models of estimating potential evapotranspiration were used.

1. **Modified Penman formula.** Potential evapotranspiration was estimated using modified Penman formula for the Philippines condition ($PET_{i(mod)}$) as presented in equation (4),
2. **Adjusted pan avaporation.** Potential evapotranspiration was estimated as follows:

$$PET_{i(adj)} = C_{pan} \times E_{i(pan)} \qquad (5)$$

where:

$PET_{i(adj)}$ = potential evapotranspiration on day i computed using adjusted pan evaporation in mm/day

C_{pan} = pan coefficient. The value of C_{pan} for Los Banos has been estimated (Anonim, 1985) at 0.85

$E_{i(pan)}$ = pan evaporation on day i in mm/day

3. **Simplified Penman formula.** Potential evapotranspiration was estimated using the Modified Penman formula with a slight modification in order to avoid reading error. Instead of using Tables 1 and 2 directly, the regression equation between the mean air temperature as independent variable (X) and slope of saturation vapor pressure (Δ), longwave losses from the earth's surface radiation ($s(T_a)^4$), and saturation vapor pressure (e_a) as dependent variable (Y) were developed using 2 models, with and without intercept. The estimated regression equation for the respective dependent variable abovementioned was developed using the data given in Tables 1 and 2, respectively. The predicted regression equation are presented in Table 4. The predicted regression equation for estimating the value of Δ, $s(T_a)^4$, and e_a was $Y = 0.0313\ X$, $Y = 10.6996 + 0.2086\ X$, and $Y = 1.3272\ X$, respectively. These regression equations were preferred due to their determination coefficient (R^2) at least equal to 0.99 and were higher than the others (Table 4).
4. **Pan evaporation.** Based on the previous study that the estimate of potential evapotranspiration computed using the modified Penman formula was significantly higher than the value of potential evapotranspiration computed using adjusted pan evaporation (Dwidjopuspito, 1986), it was reasonable that the estimate of potential evapotranspiration was assumed to be the same as pan evaporation. The daily value of pan evaporation $E_{i(pan)}$ was, therefore, directly used as an estimate of potential evapotranspiration ($PET_{i(pan)}$ as indicated in equation (6).

$$PET_{i(pan)} = E_{i(pan)} \qquad (6)$$

Table 4. Coefficient of regression and coefficient of determination (R^2) for Δ (slope of saturation vapor pressure), $s(T_a)^4$ (Boltzman constant) and saturation vapor pressure (e_a) as a function of mean air temperature (^oC)

Dependent Variable (Y)	α	β	R^2
Δ (slope of saturation vapor pressure)	-0.0760	0.0344	0.9829
	0	0.0313	0.9971*)
$s(T_a)^4$ (Boltzman constant)	10.6996	0.2086	0.9996*)
	0	0.6553	0.9550
Saturation vapor pressure (e_a)	-7.9361	1.6566	0.9744
	0	1.3272	0.9902*)

*) Selected regression equation

The modified Penman formula for the Philippines condition and an adjusted pan evaporation has been used by Dwidjopuspito (1986) to estimate the daily value of potential evapotranspiration as a component input parameter in his study of soil moisture prediction. In his recent study, these two abovementioned models would be simultaneously tested with simplified Penman formula and pan evaporation.

The daily estimate of potential evapotranspiration were computed using the data from the National Agrometeorological Station, University of the Philippines at Los Banos, which their mean values are given in Table 5.

Table 5. Mean bright sunshine to length of day ratio (n/N ratio), temperature (°C), windspeed at 2 m above the ground (km/day), relative humidity (%), and pan evaporation (mm/day) from June 1985 to January 1986 at the National Agrometeorological Station, UPLB

Months	n/N ratio	Temperature	Windspeed	Relative humidity	Pan evaporation
June	0.3922	28.66	167.25	78.57	5.1
July	0.4787	27.55	77.24	81.52	4.5
August	0.4766	28.64	104.65	75.55	5.2
September	0.3900	27.92	81.46	80.07	4.1
October	0.4314	27.63	77.76	85.58	3.6
Novemb	0.4327	27.06	80.04	84.77	3.6
Decemb	0.4223	25.64	89.94	81.58	3.2
January	0.3079	24.82	135.96	79.45	3.4
Overall	0.4208	27.32	100.38	80.94	4.1

The estimated values of potential evapotranspiration were analyzed using a completely randomized design to detect whether there was a significant effect of model used at 5 % level of significance. Duncan's Multiple Range Test was used to determine which model significantly differed to the others (Gomez and Gomez, 1984). The estimated values of potential evapotranspiration were also used as dependent variable in a stepwise regression analysis to other meteorological factors as independent variable to decide determinant factor(s) and the degree of their contribution to potential evapotranspiration.

RESULTS AND DISCUSSION

The daily average predicted potential evapotranspiration computed using an adjusted pan evaporation was 3.519 mm/day, which was significantly lower than the daily average predicted potential evapotranspiration computed using three other models (Table 6). Eventhough it was significantly lower, but the daily average predicted potential evapotrannspiration by month were not significantly different as compared to that of estimates computed using modified Penman and pan evaporation. The daily average predicted potential evapotranspiration computed using the simplified Penman formula was 4.284 mm/day, which was comparable to the daily average of pan evaporation (4.108 mm/day). These results indicate that the observed values of pan evaporation, therefore, can be directly used as an estimate of potential evapotranspiration either estimated using modified and simplified Penman formula or an adjusted pan evaporation.

Table 6. Monthly average potential evapotranspiration (mm/day) estimated using four models of potential evapotranspiration

Month	Model PET@				
	Modified	Simplified	Adjusted-pan	Pan	Overall$^{*)}$
June	4.660a	4.652a	4.440a	5.087a	4.710a
July	4.379a	4.365a	3.832a	4.519a	4.274b
August	4.846a	4.724a	4.426a	5.152a	4.787a
Septemb	4.052a	4.160a	3.457a	4.060a	3.932c
October	3.655ab	4.084a	3.065b	3.613ab	3.604cd
Novemb	3.307b	4.108a	3.133b	3.617ab	3.541d
Decemb	3.068b	4.097a	2.748b	3.239b	3.288d
January	3.264b	4.004a	2.877b	3.377b	3.381d
Overall	3.927b	4.284a	3.519c	4.108ab	

[@] In a row, means followed by a common letter are not significantly different at 5 % level by DMRT.

[*)] For this column only, means followed by a common letter are not significantly different at 5 % level by DMRT.

Results of stepwise regression analysis are given in Table 7. It shows that all independent variables used were determinant factors of the potential evapotranspiration estimated using the four models of potential evapotranspiration. The determination coefficient (R^2) of multiple linear regression equation for the modified Penman, the simplified Penman, an adjusted pan and pan evaporation was 0.8864, 0.9684, 0.5008 and 0.5032, respectively. It indicates that almost 90 % of the variablity in potential evapotranspiration computed using the modified and simplified Penman formula can be explained by the linear function of the independent variables used, whereas for adjusted pan and pan evapotranspiration only 50 % of the total variation in estimate of potential evapotranspiration can be explained by linear function of the independent variables.

The positive sign of the regression coefficient for independent variables of bright sunshine to length of day ratio, of mean air temperature and of windspeed at 2 m above the ground (Table 7), indicate that an increase value of those independent variables is always accompanied by an increase in potential evapotranspiration. The only independent variable that inhibits the rate of potential evapotranspiration is relative humidity.

Table 7. Regression coefficients and coefficient of determination (R^2) for four models of potential evapotranspiration during the course of study

	Potential Evapotranspiration			
Coefficient@	Modified	Simplified	Adjusted-pan	Pan
α	-0.0625	3.3478	-2.5975	-2.9673
β_1	2.7463	3.3348	2.5722	3.0864
β_2	0.2722	0.0634	0.2546	0.2959
β_3	0.0056	0.0047	0.0052	0.0054
β_4	-0.0392	-0.0329	-0.0301	-0.0352
R^2	0.8864	0.9684	0.5008	0.5032

@ α = regression intercept
β_1 = regression coefficient for bright sunshine to length of day ratio
β_2 = regression coefficient for mean air temperature (°C)
β_3 = regression coefficient for windspeed at 2 m above the ground
β_4 = regression coefficient for relative humidity (%)

The partial determination coefficient of meteorological factors used in the estimating potential evapotranspiration for four models are presented in Table 8. The partial determination of bright sunshine to length of day ratio, mean air temperature, windspeed at 2 m above the ground, and relative humidity was in a consistently decreasing order for four models of potential evapotranspiration, therefore, the most important determinant factor of potential evapotranspiration was bright sunshine to length of day ratio, followed by mean air temperature, windspeed at 2 m above the ground, and relative humidity at the least. The range of partial determination coefficient for bright sunshine to length of day ratio, mean air temperature, and windspeed at 2 m above the ground was 0.34 to 0.80, 0.01 to 13.0, and 0.05 to 12, respectively. Under normal environmental condition, an increase in the value of bright sunshine to length of day ratio, is always accompanied by an increase in the value of mean air temperature, and windspeed at 2 m above the ground, which are the important driving forces of potenttial evapotranspiration, as a consequence, there is an increase in potential evapotranspiration.

Table 8. Partial determination coefficients for bright sunshine to length of day ratio (n/N ratio), mean air temperature (°C), windspeed at 2 m above the ground, and relative humidity (%) in four models of potential evapotranspiration during the course of study

Independent Variable	Potential Evapotranspiration	Partial-R^2	Prob > F
n/N ratio	Modified	0.5820	0.0001
	Simplified	0.8009	0.0001
	Adjusted-pan	0.3390	0.0001
	Pan	0.3540	0.0001
Temperature	Modified	0.1259	0.0001
	Simplified	0.0080	0.0001
	Adjusted-pan	0.0734	0.0001
	Pan	0.0723	0.0001
Windspeed	Modified	0.1146	0.0001
	Simplified	0.0987	0.0001
	Adjusted-pan	0.0626	0.0001
	Pan	0.0514	0.0001
Relative humidity	Modified	0.0640	0.0001
	Simplified	0.0609	0.0001
	Adjusted-pan	0.0257	0.0007
	Pan	0.0256	0.0007

CONCLUSIONS

The results showed that:

1. The modified Penman formula, simplified Penman formula, an adjusted pan evaporation and pan evaporation had the comparable ability in estimating potential evapotranspiration; and
2. The bright sunshine to length of day ratio, mean air temperature, and windspeed at 2 m above the ground as the main constituent of driving forces of potential evapotranspiration.

On the basis of the overall results it is clear that the pan evaporation should be recommended to be used as the estimate of potential evapotranspiration, since need only the simplest procedure.

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