A Comparison of Different Models of Estimating Actual Evapotranspiration from Potential Evapotranspiration in the Dry Zone of Sri Lanka

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Abstract

This paper compares widely used methods of estimating actual evapotranspiration from potential evapotranspiration and shows that actual evapotranspiration is approximately the same irrespective of the method used to estimate it in the dry zone of Sri Lanka. This finding is in line with the findings of a similar study in UK.

Abbreviations and Notation

The abbreviations and notations used in general in this paper are explained as follows.

AKP = Angunakolapelessa (Study location)
AWC = Available water capacity of soil in the root zone (mm/m)
EMB = Embilipitiya (Study location)
ETa = Actual evapotranspiration (mm/day or mm/y)
ETp = Potential evapotranspiration (mm/day or mm/y)
F = The ratio of ETa/ETp when soil moisture deficit is greater than root constant
FC = Field capacity of soil (%)
Isc = Interception (rainfall) storage capacity (mm/day)
KAL = Kalpitiya (Study location)
MI = Maha Illuppallama (Study location)
PFc = Preferential flow co-efficient
PFt = Threshold of daily rainfall above which preferential flow occurs (mm/day)
PWP = Permanent wilting point of soil (%)
R = Rainfall (mm/day or mm/y)
RC = Root constant (% of AWC)
ROc = Runoff coefficient
ROt = Threshold of daily rainfall above which runoff occurs (mm/day)
SMD = smd = Soil moisture deficit (mm)

Introduction

Evapotranspiration is a hybrid word, comprising of the two words 'evaporation' and 'transpiration'. The term evaporation usually means the transfer of water, in the form of vapour from water and soil surfaces and from other surfaces. Transpiration is the transfer of water from vegetation to the atmosphere. The term evapotranspiration therefore, can be defined (Basnayake, 1985) as the transfer of water in the form of vapour from the earth's surface including soil, vegetation and ocean surfaces, to the atmosphere.

A distinction needs to be made between the 'potential evapotranspiration' and the 'actual evapotranspiration'. The former is defined as the evaporative demand of the atmosphere. The latter is defined as the actual amount of water evaporated and transpired from soil, precipitation from plants to meet the evaporative demand of the atmosphere. When there is no shortage of water to the vegetation (or when there is enough water available for evaporation) the actual evapotranspiration will be equal to the potential evapotranspiration.

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The study of actual evapotranspiration is important in studies of hydrological balance of a catchment, estimating deep percolation to aquifers, scheduling irrigation to crops and in a host of other applications.

This paper therefore compares 4 different models commonly used for estimating actual evapotranspiration from potential evapotranspiration by estimating actual evapotranspiration with these 4 different models at different locations in the dry zone of Sri Lanka and comparing them objectively.

Estimating actual evapotranspiration (ETa)

There are many ways of estimating actual evapotranspiration. The ones used more commonly are discussed below.

Lerner et al., (1990) suggest the Penman-Monteith model (equation 1) as the best to estimate actual evapotranspiration in humid climates.

$$ETa = \frac{[s.H + c.d.(e_a - e_d)/r_a]}{l.[s + g.(1 + r_s/r_a)]} \text{..................} (1)$$

In equation 1, s is the slope of saturated vapour pressure curve, H is available energy, c is specific heat of air, d is density of air, e_a is saturated vapour pressure at air temperature, e_d the vapour pressure at screen height, r_a the aerodynamic resistance, r_s the stomatal resistance, l is latent heat of vaporisation and g is the psychometric constant. However, this method is rarely used because of the difficulty of estimating the aerodynamic and stomatal resistance parameters.

A different approach is to estimate the potential evapotranspiration (ETp), and use this parameter to estimate actual evapotranspiration.

To estimate Potential evapotranspiration, an empirical method (such as the Blaney-Criddle method and the Radiation method) or a semi empirical method (Penman method) can be used. However, these methods need temperature, humidity, wind speed, sunshine and radiation data to estimate the potential evapotranspiration.

A different method to estimate potential evapotranspiration is to measure the evaporation from a pan (121 cm diameter and 25.5 cm deep) placed on a wooden platform with the bottom of the pan 15 cm from the ground. This measure called pan evaporation is converted to potential evapotranspiration by multiplying by a pan coefficient (Kp), depending on climatological, vegetative and wind factors (Doorenbos and Pruitt, 1977).

The Penman-Grindley model (equation 2) is a widely used method for estimating actual evapotranspiration from potential evapotranspiration [Lerner et al., (1990)].

$$\begin{aligned}
&\text{If } SMD < RC \text{ or } ETp <= R,\ ETa = ETp \\
&\text{If } AWC < SMD <= RC \text{ and } ETp > R,\ ETa = R + F.(ETp - R) \text{ ....} (2) \\
&\text{If } SMD = AWC \text{ and } ETp > R,\ ETa = R
\end{aligned}$$

Here SMD = the soil moisture deficit of the root zone, RC = root constant (defined later), R= rainfall, F = ratio of ETa/Etp, when the soil moisture deficit is greater than the root constant. In this method a root constant, [RC; defined as the soil moisture deficit at which actual evapotranspiration (ETa) falls below the potential evapotranspiration (ETp)] and a ratio of ETa/ETp (= F) are required to estimate actual evapotranspiration. For agricultural crops (cereals, potatoes, vegetables and grasses), other vegetation (grazing and woodlands), bare fallow lands and riparian zones the values of the root constant are different and the relevant values for each month in UK are available (Grindley, 1969).

The value of F is considered as 10% for UK climatic and soil conditions (Lerner et al., 1990). Fig. 1 shows the variation of the value of F with soil moisture deficit in graphical form for climatic, vegetative and soil conditions in UK.

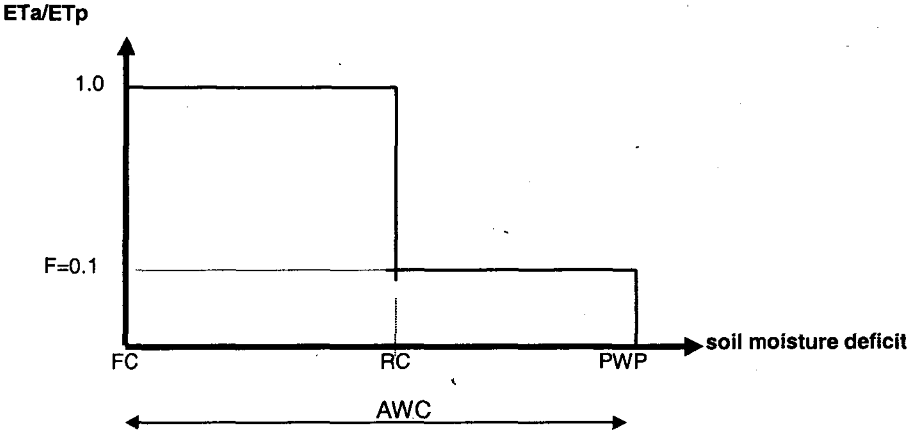


Fig. 1 Penman-Grindley model for estimating actual evapotranspiration

Calder et al., (1983), Baier et al., (1979) and Rushton and Ward (1979) describe some other relationships between actual evapotranspiration and potential evapotranspiration (when soil moisture deficit > root constant) as shown in Fig. 2.

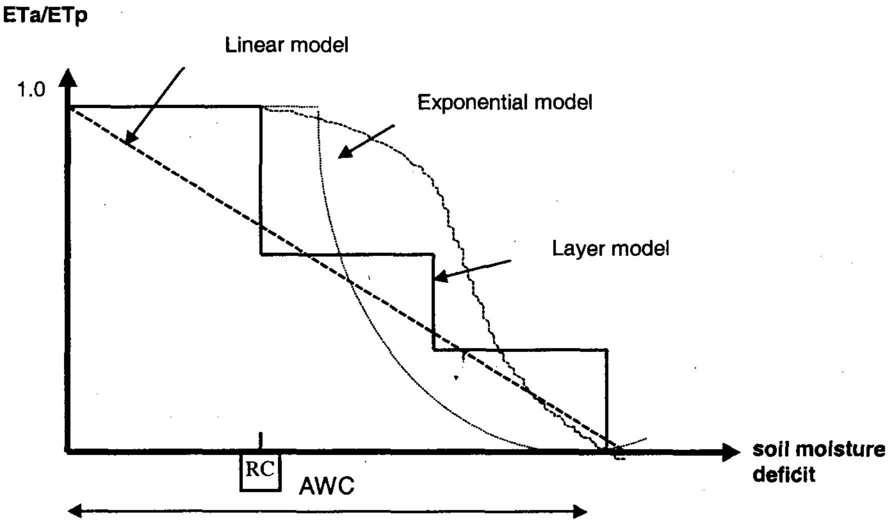


Fig. 2 Different models for estimating actual evapotranspiration

Doorenbos and Kassam, (1979) describe a model (as shown in Fig. 3), which assumes a linear reduction of F. By taking critical deficit = 0, this model becomes effectively the same linear model described by Calder et al., (1983) and Rushton and Ward (1979) in Fig. 2.

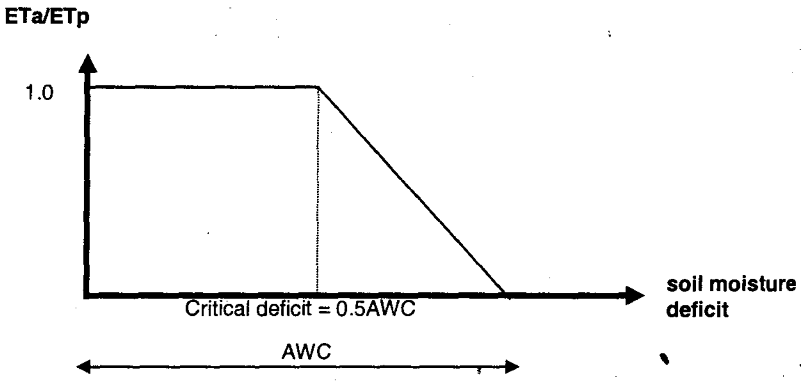


Fig.3 Model by Doorenbos and Kassam, (1979) to estimate actual evapotranspiration (AWC = Available water capacity = maximum soil moisture deficit possible in the root zone)

It is also noted that Calder et al., (1983) compared 7 different drying curves to estimate actual evapotranspiration in UK and have concluded that little is gained by using detailed models requiring a lot more information.

The objective of this paper is therefore, to compare 4 commonly used models (in Figs. 1,2 and 3) which are required to estimate ETa from ETp using the Penman-Grindley model (equation 2). The chosen models are shown in Fig. 6 (a), (b), (c) and (d) respectively.

Materials and Methods

The methodology adopted is as follows.

(a). Select suitable locations.

(b). Collect all relevant data (i.e., daily rainfall and pan evaporation for a few years, information on rainfall interception, runoff and preferential flow).

(c). Experimentally determine the field capacity and permanent wilting point of soil and also observe the type of vegetation and depth of roots at each location.

(d). Form a suitable soil water budget model to determine the soil moisture deficit as this parameter is required to estimate the actual evapotranspiration (equation 2).

(e). Estimate actual evapotranspiration from different methods and compare them statistically to see if they are significantly different from each other.

The locations chosen in the dry zone are shown in Fig. 4 along with the mean annual rainfall distribution and mean annual pan evaporation distribution for each location. In choosing these locations, the factors considered were the availability of climatic data and the different types of soil types and vegetation. Climatic, soil and vegetation details at the study locations are shown in Table 1.

Table 1. Details of locations in the dry zone

Location	No in Map (Fig. 4)	Mean Annual Rain[1] (mm/y)	Mean Annual Pan Evaporation[1] (mm/y)	Vegetation	Major Plant type	Top soil
Embilipitiya	1	1397	1729[2]	Shrub jungle	Maana (Grass about 30 cm tall)	Loamy Sand
Angunakola-pellessa	2	1041	1868	Shrub jungle	Eraminiya (Bush about 1.5 m tall)	Sandy Clay Loam
Maha Illuppallama	3	1305	1579	Jungle	-	Loamy Sand
Kalpitiya	4	955	1958[3]	Sparse Jungle	Bolpana (Tree about 3m tall)	Sand

[1] 6 year mean value except for Angunakolapellessa, where the mean value is the 17 year one.

[2] Pan evaporation values are from the climate station at Sevanagala (ie, the nearest agro-climatic station).

[3] Pan evaporation value are from climate station at Vanathavillu (ie, the nearest station where evaporation data is available).

Details of climatic data are presented in de Silva (1996). The number of years these data collected are given in Table 2. The soil properties at each site (which were experimentally determined) are also shown in Table 2.

Table 2. Soil properties at each location of this study

Location	No of sampling points in the site	Depth to water table (m)	No of years daily rainfall data collected	No of years daily pan evaporation data collected	Root zone depth (m)	Field Capacity (%)	Permanent Wilting Point (%)
Embilipitiya	8	>2.9	6 (1989-1994)	6 (1989-1994)	0.69	21.4	15.7
Angunakola pell-essa	12	>4.1	6 (1976-1981)	6 (1976-1981)	0.95	20.2	12.0
Maha Illuppallama	12	>3.2	6 (1986-1991)	6 (1986-1991)	1.17	20.9	11.0
Kalpitiya	5	2.3	6 (1970-1975)	6 (1970-1975)	1.50	14.00	04.00

(Note : The number of years rainfall and pan evaporation data collected for different locations differ as the computerised data were available for these years only. Also in some cases the data were available for more years, but, overlapping years for both types of data could be obtained for these years only. The study could have been made for 10 years of daily data, had it been available, but the end result is unlikely to differ as will be seen later.)

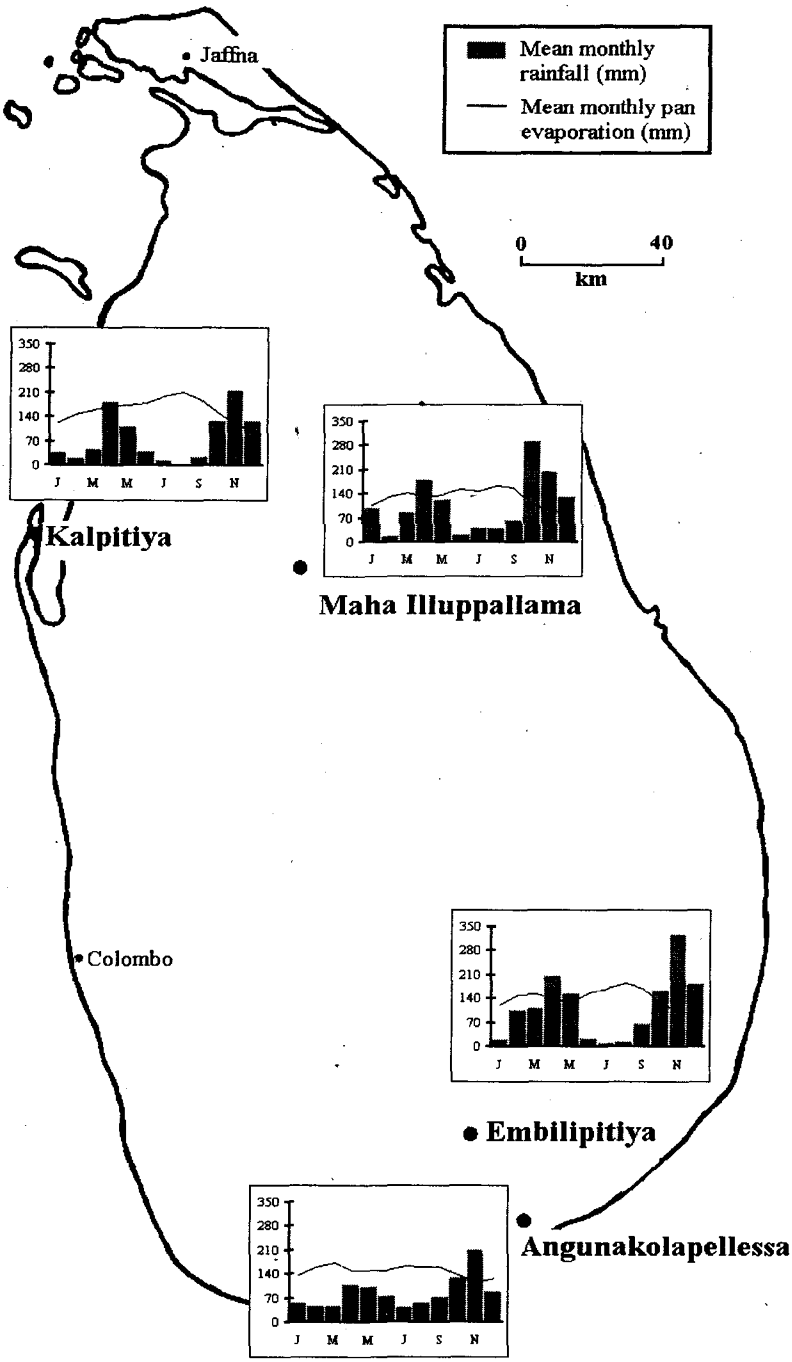


Fig. 4 - Study locations in the dry zone of Sri Lanka (Mean monthly rainfall and pan evaporation for each location is also shown).

A soil water budget model to calculate the soil moisture deficit, which is required to estimate the actual evapotranspiration (equation 2), was formed and the flow chart is shown in Fig. 5. A detailed explanation of the soil water budget model is given in de Silva (1996) with an explanation of the spreadsheet model used for the calculations.

As seen from Fig. 5, parameters of rainfall interception storage capacity (Isc), Runoff threshold (ROt), runoff coefficient (ROc), Preferential flow threshold (PFt), Preferential flow coefficient (PFc) and root constant (RC) for a particular location are required for the soil water budget model. Table 3 shows the values of these parameters obtained by considering the vegetation, rainfall distribution and soil types at each location. A detailed explanation of obtaining these parameters for each location are given in de Silva (1996).

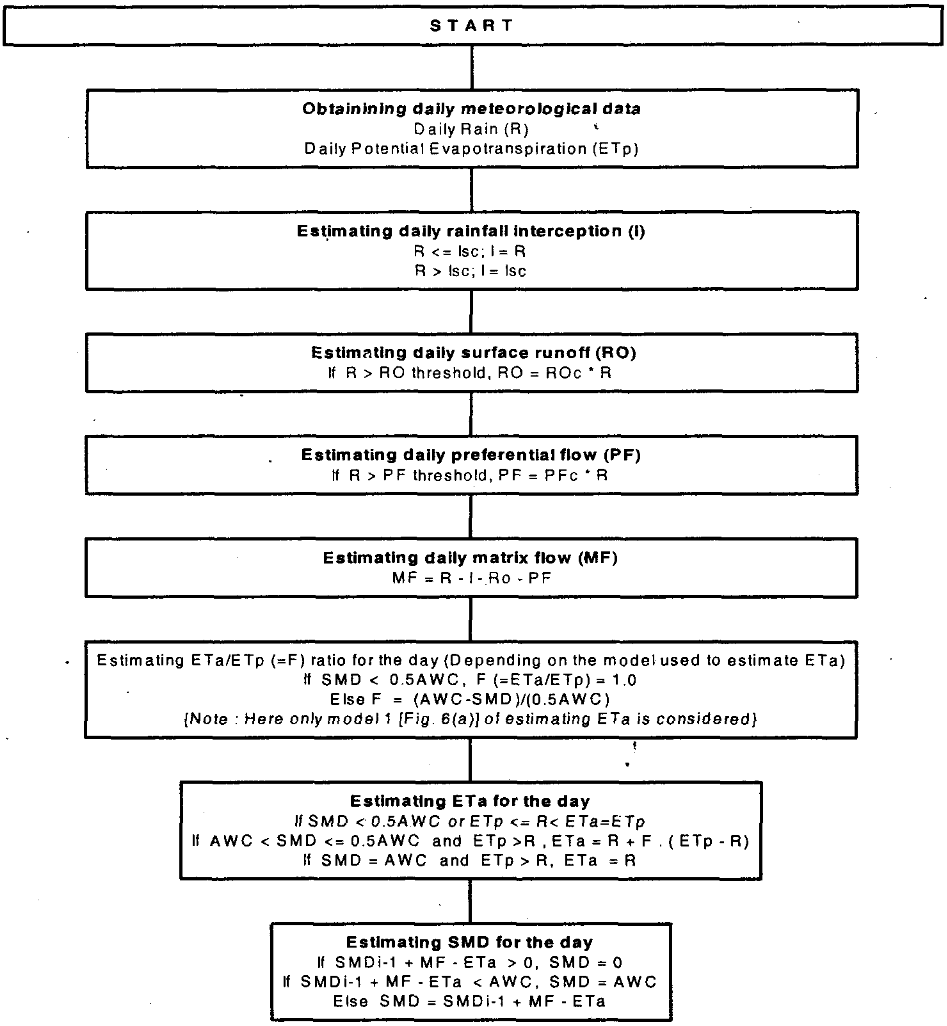


Fig. 5 Flow chart of the soil water budgeting model to estimate soil moisture deficit

Table 3 Rainfall interception storage capacity (Isc), Runoff threshold (ROt), runoff coefficient (ROc), Preferential flow threshold (PFt), Preferential flow coefficient (PFc) and root constant (RC) for the study locations.

Location	Isc	ROt	ROc	PFt	PFc	RC
Embilipitiya	1.8	12.5	0.25	10	0.075	50% of AWC
Angunakolapelessa	1.6	12.5	0.32	10	0.075	50% of AWC
Maha Illuppallama	2.0	12.5	0.27	10	0.075	50% of AWC
Kalpitiya	1.2	15.0	0.00	10	0.075	50% of AWC

The 4 models chosen to estimate F (i.e., the ratio of ETa/ETp when SMD>RC) are graphically shown in Fig. 6(a), (b), (c) and (d) with the corresponding equations describing each model mathematically.

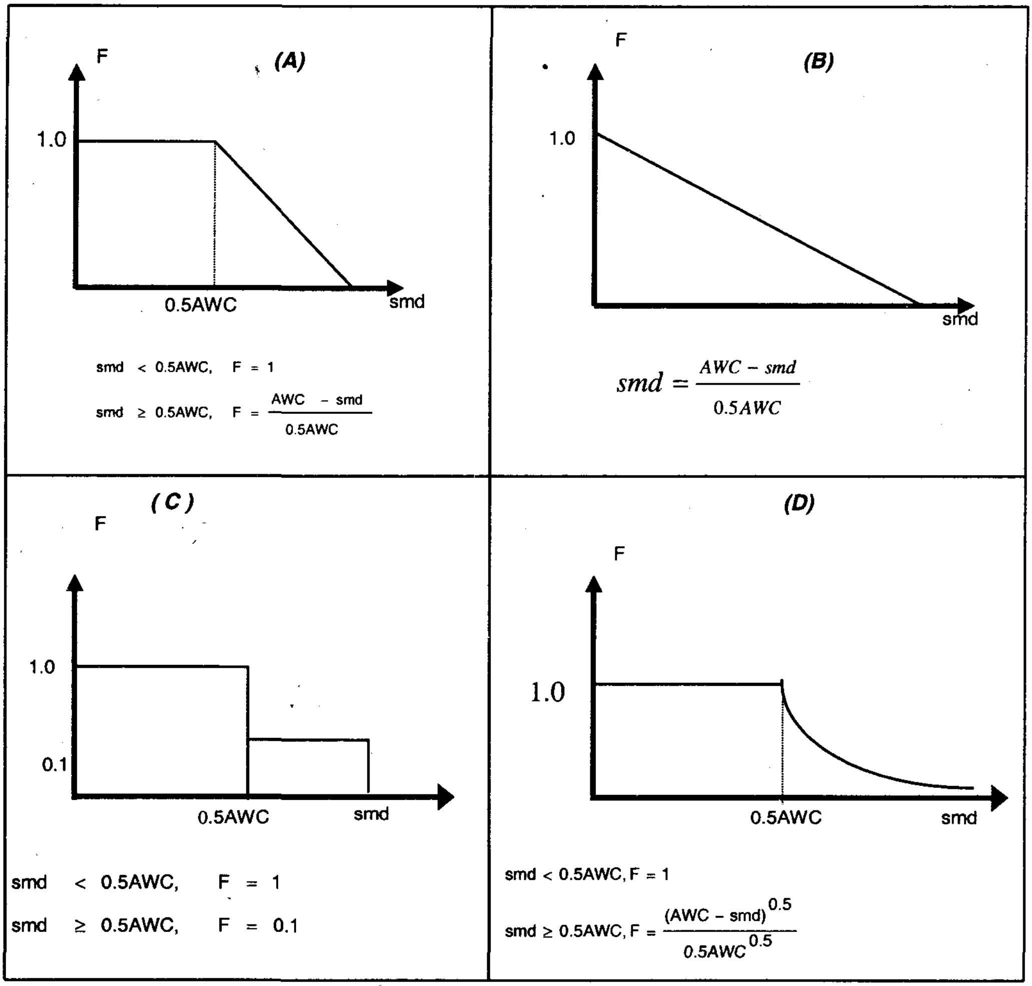


Fig. 6 (a), (b), (c) and (d) Graphical and mathematical representation of the 4 models of estimating ETa from ETp used in this study

Results

The climatic data were fed into the soil water budget model shown in Fig. 5 for all 4 models and some of the results obtained are given in Tables 4 and 5 and in Figs. 7 and 8. Table 4 shows the annual estimates of ETa for the 4 different location with 4 different models of estimating ETa in the dry zone considering 6 years of daily data (Periods considered are given in Table 2). Table 5 shows the estimates of ETa for Angunakolapelessa for different years from 1976 to 1981 with the 4 different models.

As seen from Tables 4 and 5, the estimates of ETa are similar with all the 4 models for different locations and also for one location in different years. To test if the very small differences are significant, an analysis of variance test can be carried out. Tables 6 and 7 show the results of analysis of variance test at 5% significant level. As seen from these two Tables, the differences are not significant at 5% as Fcalc is less than Fcrit; rejecting the null hypothesis that the values are different (Gomez and Gomez, 1976). However, the distribution of ETa with time also need to be compared to see if all the models produce a similar result (i.e., comparing annual values of ETa is not sufficient).

Table 4 - Actual evapotranspiration estimated from 4 different models for 4 different locations.

Location	Period considered	Rain (mm/y)	ETp (mm/y)	Actual Evapotranspiration (mm/y)			
				Model 1	Model 2	Model 3	Model 4
EMB	1989-1994	1397	1729	657	638	610	667
AKP	1976-1981	1048	1920	589	579	562	597
MI	1986-1991	1305	1579	680	668	639	686
KAL	1970-1975	955	1960	687	672	649	698

Table 5 - Actual evapotranspiration estimated with 4 different models for Angunakolapelessa for different years.

Year	Rain (mm/y)	ETp (mm/y)	Actual Evapotranspiration (mm/y)			
			Model 1	Model 2	Model 3	Model 4
1976	1020	2015	489	477	475	496
1977	1182	1695	650	643	621	660
1978	993	1866	581	571	551	589
1979	1124	1748	662	657	642	666
1980	1137	2056	641	628	600	653
1981	830	2140	508	496	484	516

Table 6 Analysis of variance test results for comparing estimates of ETa in Table 4

Source of Variation	Sum of squares	Degrees of freedom	Mean squares	Fcalc	F crit
Between Groups	5042.13	3	1680.71	0.91	3.49
Within Groups	22185.71	12	1848.81		
Total	27227.84	15			

Table 7 Analysis of variance test results for comparing estimates of ETa in Table 5

Source of Variation	Sum of squares	Degrees of freedom	Mean squares	Fcalc	F crit
Between Groups	4020.4	3	1340.14	0.24	3.10
Within Groups	112242.2	20	5612.11		
Total	116262.6	23			

Fig. 7 and 8 shows the distribution of ETa over a period of one year for Angunakolapelessa and Maha Illuppallama respectively with the 4 different models. An analysis of variance test can be carried out to see if these distributions are significantly different or not.

Tables 8, 9, 10 and 11 show the results of analysis of variance tests to see if distributions of ETa estimates are significantly different or not. In this test the daily estimates of ETa for 6 years were considered. Here again, the distributions at each location are significantly not different at 5% as Fcalc is less than Fcrit in Tables 8, 9, 10 and 11.

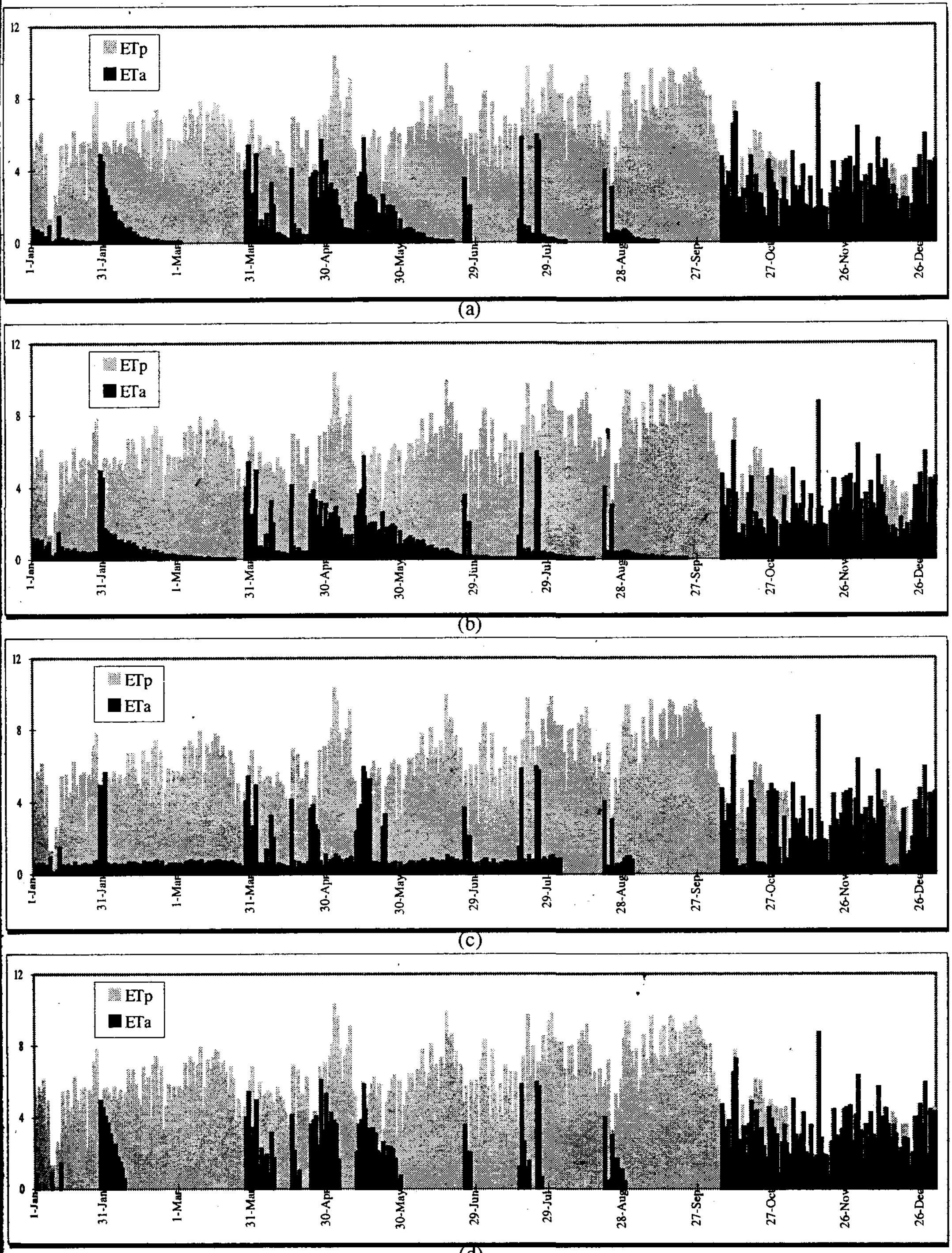
Therefore, it is concluded that from the evidence shown in this study, the 4 commonly used models of estimating ETa from ETp produce almost the similar result and in estimating ETa from ETp, any of these models may be used.

Table 8 Analysis of variance for ETa distribution by 4 different models at Embilipitiya

Source of Variation	Sum of squares	Degrees of freedom	Mean squares	Fcalc	F crit
Between Groups	31.17	3	10.39	2.44	2.60
Within Groups	37176.69	8764	4.24		
Total	37207.87	8767			

Table 9 Analysis of variance for ETa distribution by 4 different models at Angunakolapelessa

Source of Variation	Sum of squares	Degrees of freedom	Mean squares	Fcalc	F crit
Between Groups	11.06	3	3.68	1.09	2.60
Within Groups	29617.55	8764	3.37		
Total	29628.61	8767			



(a)

(b)

(c)

(d)

Fig. 7 (a), (b), (c) and (d) Potential Evapotranspiration (ETp) and Actual evapotranspiration (ETa) estimated with different models for Angunakolapelissa for the year 1976. (ETp and ETa values are in mm)

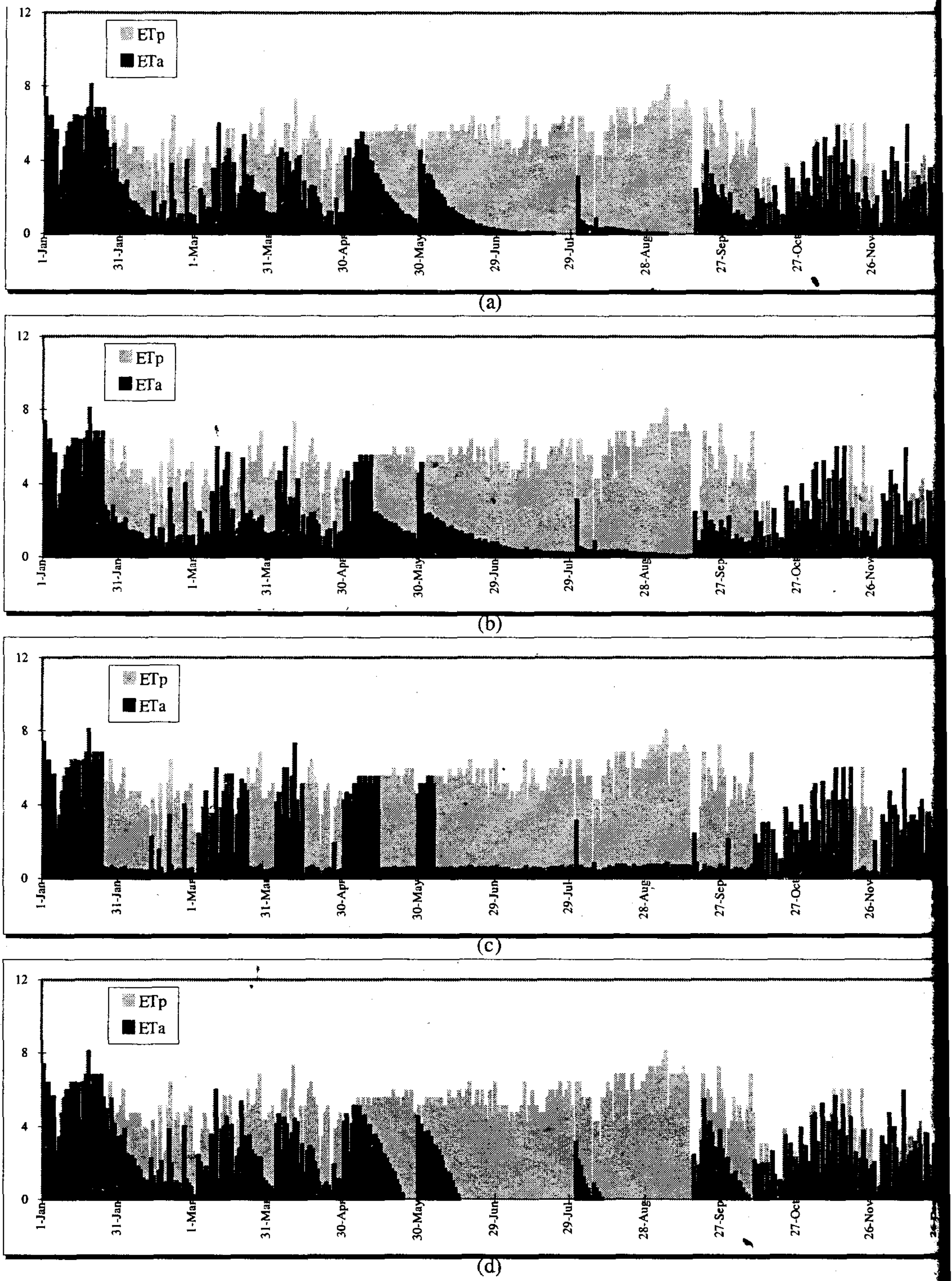


Fig. 8 (a), (b), (c) and (d) Potential Evapotranspiration (ETp) and Actual evapotranspiration (ETa) estimated with different models for Maha Illuppallama for the year 1986. (ETp and ETa values are in mm)

Table 10 Analysis of variance for ETa distribution by 4 different models at Maha Illuppallama

Source of Variation	Sum of squares	Degrees of freedom	Mean squares	Fcalc	F crit
Between Groups	21.54	3	7.18	2.58	2.60
Within Groups	24365.49	8764	2.78		
Total	24387.04	8767			

Table 11 Analysis of variance for ETa distribution by 4 different models at Kalpitiya

Source of Variation	Sum of squares	Degrees of freedom	Mean squares	Fcalc	F crit
Between Groups	22.03	3	7.34	1.59	2.60
Within Groups	40275.11	8764	4.59		
Total	40297.15	8767			

Concluding Discussion

This paper estimates the actual evapotranspiration at 4 locations in the dry zone of Sri Lanka with 4 commonly used models (of estimating ETa from ETp). The results clearly demonstrate the estimates of actual evapotranspiration (both the annual values and the distribution with time for 6 years) are independent of the method used. Therefore, it is evident that any of the methods that are commonly used to estimate ETa from ETp can be safely be used to estimate ETa from ETp in the dry zone of Sri Lanka.

It is interesting to note that Calder et al (1983) found a similar result from a study in UK, where he concludes that measuring rainfall and potential evapotranspiration is more important than placing the importance on the selection of models to use. From this study, it is evident that this statement is true for the dry zone of Sri Lanka as well.

A simplification was used in using the parameters (of estimating interception storage coefficient, runoff coefficient and threshold and preferential flow threshold and coefficient) as fixed values shown in Table 3 were used. (These values are the best one can arrive at the moment with the information available for interception of rainfall by vegetation, run off of rainfall and preferential flow). This simplification is not thought to affect the result significantly. However, it will be interesting to see the effect of different values of these parameters on the final result.

This study can be repeated for other locations in the dry zone to check on the conclusion of this study. However, the locations chosen in this study are typical for the dry zone, it is thought that the conclusions one can arrive at are as same as in this study.

This finding has important practical implications in many issues such as in the assessment of safe groundwater yield in aquifers, irrigation scheduling to crops and in the studies of hydrological and hydro-geological balance of catchments.

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