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ESTIMATING GROUNDWATER RECHARGE IN THE DRY ZONE OF SRI LANKA USING WEEKLY, 10-DAILY OR MONTHLY EVAPOTRANSPIRATION DATA

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Howard and Lloyd (1979) have shown that daily values for rainfall and potential evapotranspiration are required in estimating recharge with a soil water balance model. However, available data may not be daily but weekly or even monthly. This is true for potential evapotranspiration data which are usually derived from pan evaporation data. This paper examines the effect of using distributed weekly, 10-daily or monthly potential evapotranspiration values rather than the actual daily values in estimating recharge with a soil water balance model. The results clearly show that in the dry zone of Sri Lanka, the evenly distributed weekly, 10-daily or even monthly potential evapotranspiration data can be used in a soil water balance model to obtain realistic groundwater recharge estimates, instead of actual daily potential evapotranspiration data.

INTRODUCTION

Groundwater recharge is defined as the rate of replenishment of the water table. This rate of replenishment is the essential parameter one needs to know for sustainable development of the groundwater resource, as a drop of water table to greater depths (often to uneconomical pumping levels), degradation of quality of groundwater (especially near the coast) and other ill effects would result from developing the groundwater resource without due consideration given to recharge in the planning stage.

A number of methods are available for the estimation of recharge to an aquifer (Allison et al., 1994; Hendricks and Walker, 1995; de Silva, 1996). Methods of estimating recharge can be broadly grouped into physical and chemical methods. Physical methods include (a) lysimeters, (b) soil water balance models, (c) the water table fluctuation method, (d) the catchment water balance method, (e) the numerical modelling of the unsaturated zone (f) the zero flux plane method and (g) the Darcy method. Chemical methods include (h) the tritium method and (i) the chloride method.

Of these methods, the soil water balance method is a simple method for estimating recharge in most conditions and quite often is the only suitable method (de Silva, 1996; Lerner et al, 1990). In this method, a volume balance for water entering and leaving the root zone and change in soil moisture storage is carried out and recharge (Re) is estimated as;

$$Re = P - I - RO - ETa \pm \Delta S \tag{1}$$

where P is precipitation, I is interception of rainfall by vegetation, RO is runoff, ETa is actual evapotranspiration and ΔS is change in soil moisture storage. If the balance is carried out annually (especially from the end of the rainy season to the same time the following year), the change in soil moisture storage is negligible. Therefore Equation (1) reduces to;

$$Re = P - I - RO - ETa \tag{2}$$

The time step for carrying out this balance is usually a single day (Howard and Lloyd, 1979) for the input time variables of rainfall and potential evapotranspiration (ETp) , obtained by multiplying the pan evaporation values with a coefficient. However, some research workers have used monthly or weekly data converted to daily data by dividing the monthly value by 30 or by dividing the weekly value by 7 instead of actual daily data (Howard and Karundu, 1992; De Silva, 1995).

This paper investigates the effect of using monthly, 10-daily or weekly data (divided by 30, 10, or 7 respectively to convert to daily data) in a soil water balance model, instead of the actual daily ETp data. Since daily rainfall data is often available, only the effect of monthly, 10-daily and weekly potential evapotranspiration data is investigated.

MATERIALS AND METHODS

The methodology adopted is as follows.

(a) Select suitable study locations in the dry zone of Sri Lanka.

(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 balance model to estimate recharge.

(e) Estimate recharge with monthly, 10-daily and weekly values of ETp and compare them with the estimates of recharge for daily values of ETp to see the effect of using monthly, 10-daily and weekly values of ETp in a soil water balance model.

The locations chosen in the dry zone are shown in Figure 1, 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.

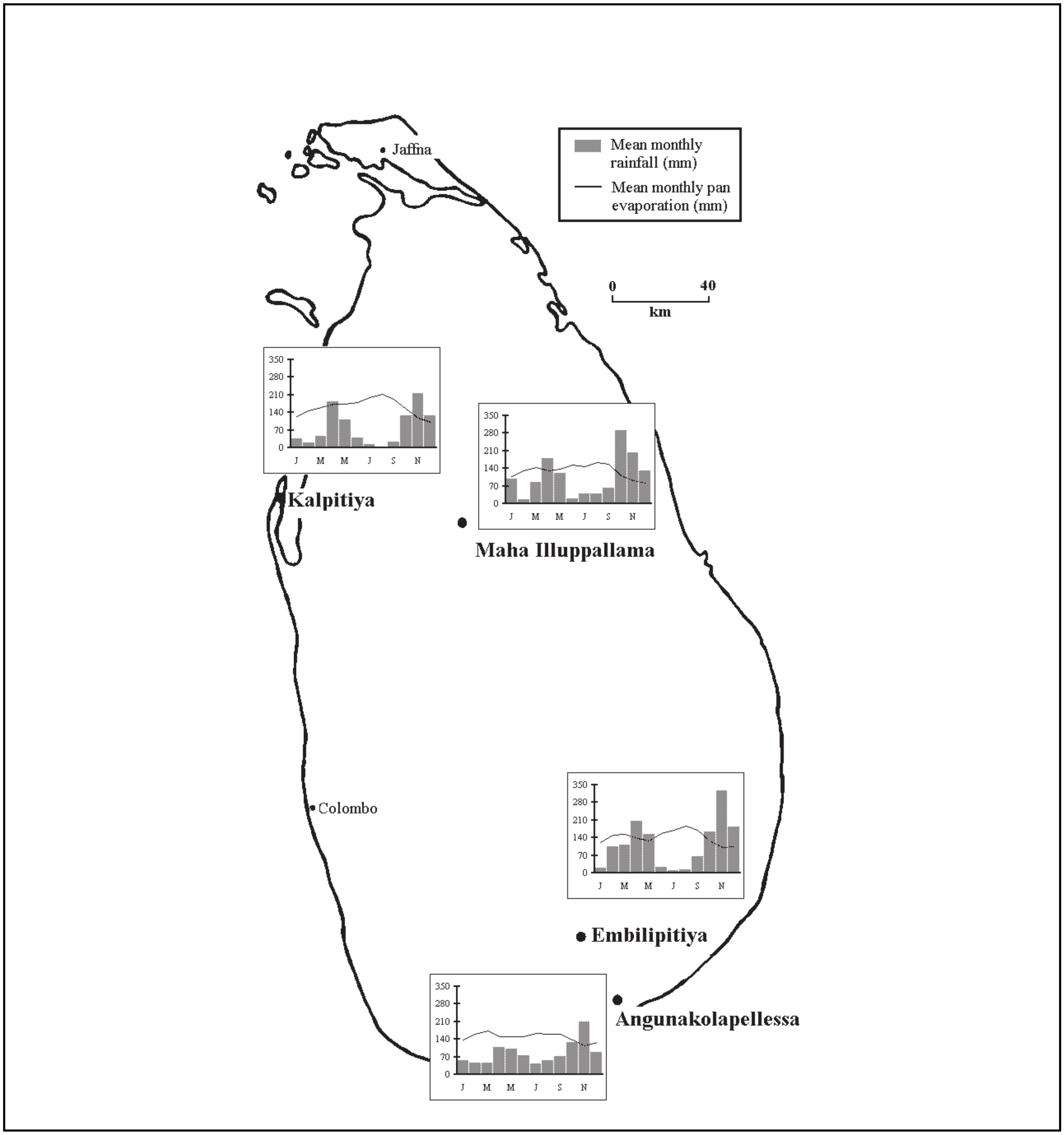

Figure 1. Study locations in the dry zone of Sri Lanka (mean monthly rainfall and pan evaporation for each location is also shown).

Table 1. Details of Locations in the Dry Zone

Location	Mean Annual Rain[1] (mm/y)	Mean Annual Pan Evaporation[1] (mm/y)	Vegetation	Major Plant type	Top soil
Embilipitiya	1397	1729[2]	Shrub jungle	Maana (Grass about 30 cm tall)	Loamy Sand
Angunakolapellessa	1041	1868	Shrub jungle	Eraminiya (Bush about 1.5 m tall)	Sandy Clay Loam
Maha Illuppallama	1305	1579	Jungle	-	Loamy Sand
Kalpitiya	955	1958[3]	Sparse Jungle	Bopana (Tree about 3 m 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 (i.e., the nearest agro-climatic station).
[3] Pan evaporation values are from climate station at Vanathavillu (i.e., the nearest station where evaporation data is available).

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

The soil water balance model formed to estimate groundwater recharge is shown in Figure 2. A detailed explanation of the soil water balance model is given in de Silva (1996) with an explanationofthe spreadsheet model used for the calculations.

Table 2. Soil Properties at Each Location of This Study

Location	No of sampling points	Depth to water table (m)	No of years daily rainfall	No of years daily pan evaporation	Root zone depth (m)	Field Capacity (%)	Permanent WiltingPoint (%)
Embilipitiya	8	>2.9	6 (1989-1994)	6 (1989-1994)	0.69	21.4	15.7
Angunakolapellessa	12	>4.1	17 (1976-1992)	17 (1976-1992)	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	14.0	4.0

As seen from Figure 2, 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 balance 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 is given in de Silva (1996).

To compare estimates of recharge with different distributions of ETp, actual daily data was

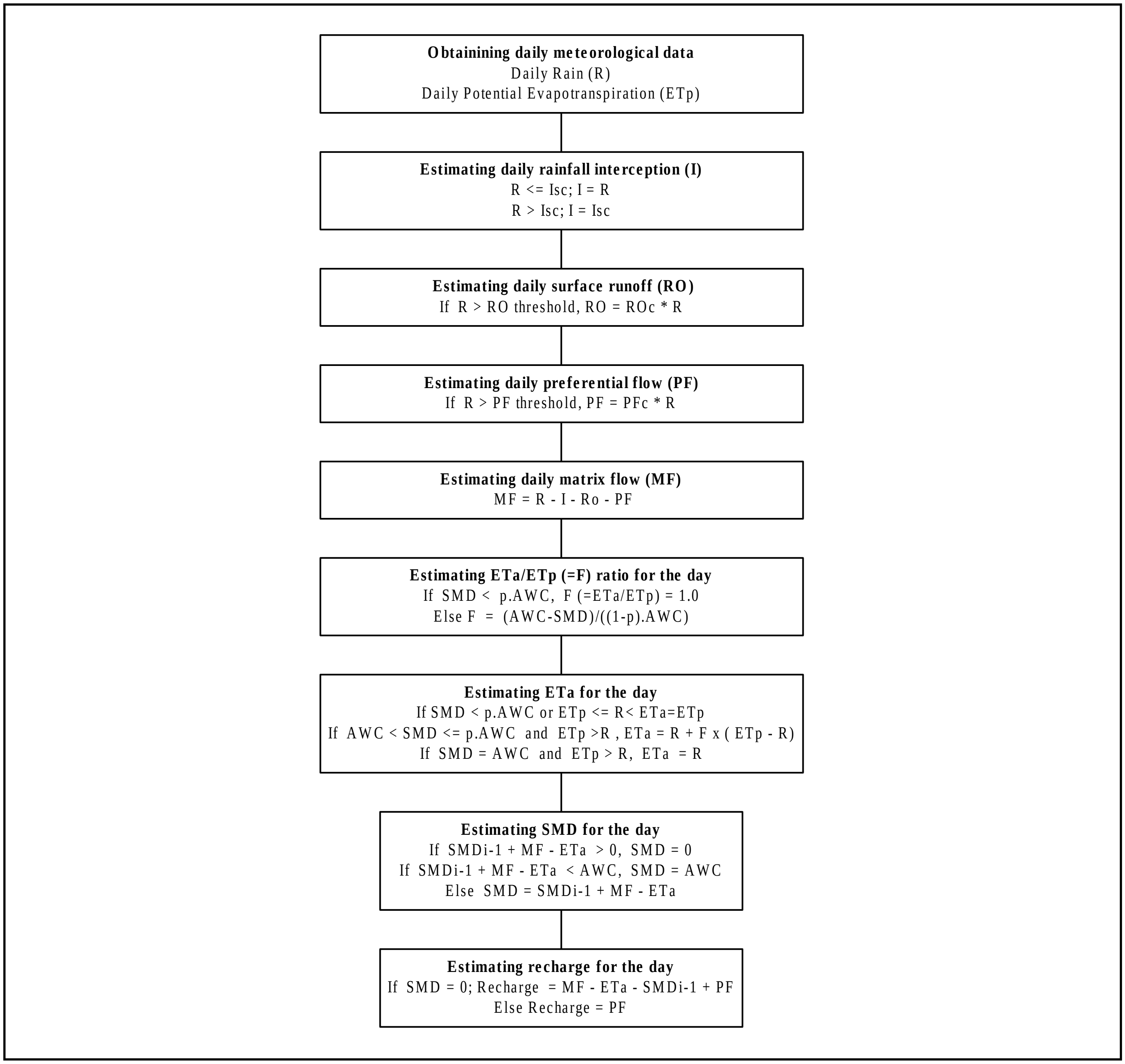

Figure 2. Flow chart of the soil water balance model to estimate soil moisture deficit.

converted to weekly, 10-daily and monthly ETp data by summing up the daily values over periods of 7, 10 and 30 days. These monthly values were then converted to daily data by dividing by 7, 10, and 30 respectively.

Table 3. Rainfall Interception Storage Capacity (Isc), Runoff Threshold (ROc), 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

RESULTS

Table 4 shows the estimates of groundwater recharge for the 4 study locations in the dry zone, with potential evapotranspiration distributions for daily (Distr. 1), weekly (Distr. 2), 10-daily (Distr. 3) and monthly (Distr. 4) data. As seen from Table 4, the difference between recharge estimates for a particular location with different distributions of ETp is negligible.

Table 4. Estimates of Groundwater Recharge for Different Locations Using the Four Different Distributions of ETp

Location	Period considered	Rain (mm/y)	ETp (mm/y)	Groundwater Recharge (mm/y)			
				Distr. 1	Distr. 2	Distr. 3	Distr. 4
EMB	1989-1994	1397	1729	331	330	330	321
AKP	1976-1981	1048	1920	90	89	87	84
MI	1986-1991	1305	1579	193	191	191	187
KAL	1970-1975	955	1960	179	178	178	172

Table 5 shows the estimates of groundwater recharge for Angunakolapelessa for different years with different distributions of ETp. Even here, the difference between the recharge estimates is negligibly small.

Table 5. Estimates of Groundwater Recharge at Angunakolapellessa for Different Years Using the Four Different Distributions of ETp

Year	Rain (mm/y)	ETp (mm/y)	Groundwater Recharge (mm/y)			
			Distr. 1	Distr. 2	Distr. 3	Distr. 4
1976	1020	2015	129	126	125	122
1977	1182	1695	140	141	135	135
1978	993	1866	78	78	73	65
1979	1124	1748	45	45	42	39
1980	1137	2056	106	102	101	100
1981	830	2140	45	45	45	42

Although the differences of recharge estimates in Tables 4 and 5 are rather small, an analysis of variance test can be conducted to see if these differences are statistically significant. Tables 6 and 7 show the results of an analysis of variance test for differences in Tables 4 and 5. The differences are not significant at 5 percent as Fcalc is less than Fcrit; rejecting the null hypothesis that the values are different (Gomez and Gomez, 1976).

However, the distribution of recharge with time also needs to be compared to see if all the distributions of ETp produce a similar result (i.e., comparing annual values of recharge is not sufficient).

Table 6. Analysis of Variance Test Results for Comparing the Estimates of Recharge in Table 4

Source of Variation	**Sum of squares**	**Degrees of freedom**	**Mean squares**	**Fcalc**	**F crit**
Between Groups	120.97	3	40.32	0.004	3.49
Within Groups	118256.9	12	9854.73		
Total	118377.8	15			

Table 7. Analysis of Variance Test Results for Comparing the Estimates of Recharge in Table 5

Source of Variation	**Sum of squares**	**Degrees of freedom**	**Mean squares**	**Fcalc**	**F crit**
Between Groups	158.99	3	52.99	0.031	3.09
Within Groups	33295.74	20	1664.78		
Total	33454.73	23			

Figures 3 and 4 show the distribution of recharge over a period of six years for study locations Angunakolapelessa and Kalpitiya respectively with the four different ETp distributions. An analysis of variance test was carried out to see if these distributions are significantly different, and the results are shown in Tables 8, 9, 10 and 11.

In this test the daily estimates of recharge for six years were considered. Here again, the recharge distributions at each location are not significantly different at 5percent as Fcalc is less than Fcrit.

Table 8. Analysis of Variance Test Results for Comparing the Distributions of Recharge by Four Different ETp distributions at Embilipitiya

Source of Variation	**Sum of squares**	**Degrees of freedom**	**Mean squares**	**Fcalc**	**F crit**
Between Groups	1.07	3	0.35	0.012	2.60
Within Groups	241786.8	8764	27.58		
Total	241787.9	8767			

Table 9. Analysis of Variance Test Results for Comparing the Distributions of Recharge by Four Different ETp distributions at Angunakolapellessa

Source of Variation	**Sum of squares**	**Degrees of freedom**	**Mean squares**	**Fcalc**	**F crit**
Between Groups	0.43	3	0.14	0.024	2.60
Within Groups	50956.55	8764	5.81		
Total	50956.99	8767			

CONCLUSIONS

As seen from the analysis of results, the effect of using distributed ETp values (instead of actual daily ETp values) in a soil water balance model for estimating groundwater recharge is negligible in the dry zone of Sri Lanka. Therefore, it is concluded that wherever pan evaporation data is available (weekly, 10-daily or monthly), these data can be divided by 7, 10, or 30 respectively to convert them

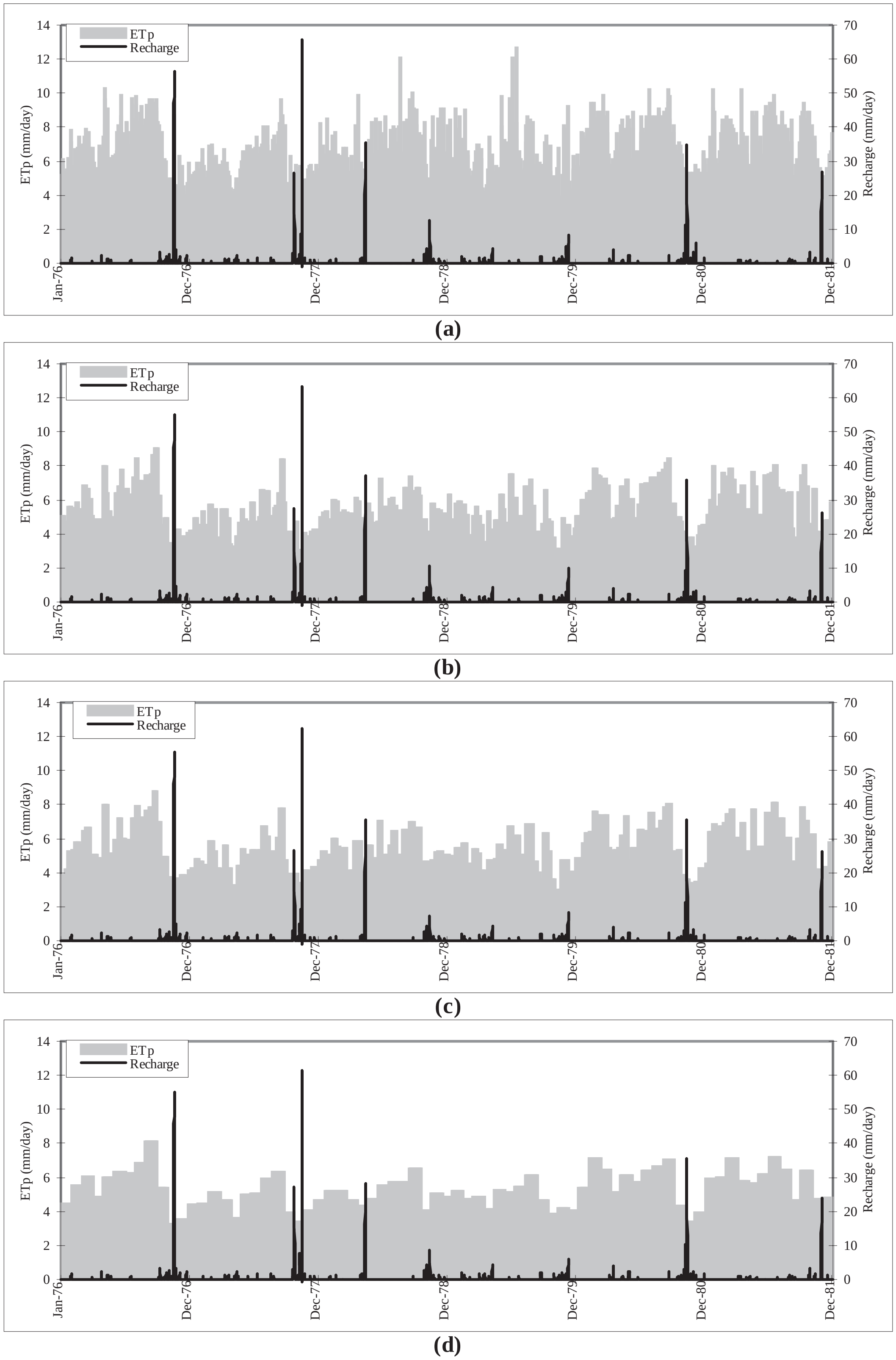

Figure 3. Potential evapotranspiration (ETp) and recharge estimated with four different ETp distributions for Angunakolapelessa from 1976-1981.

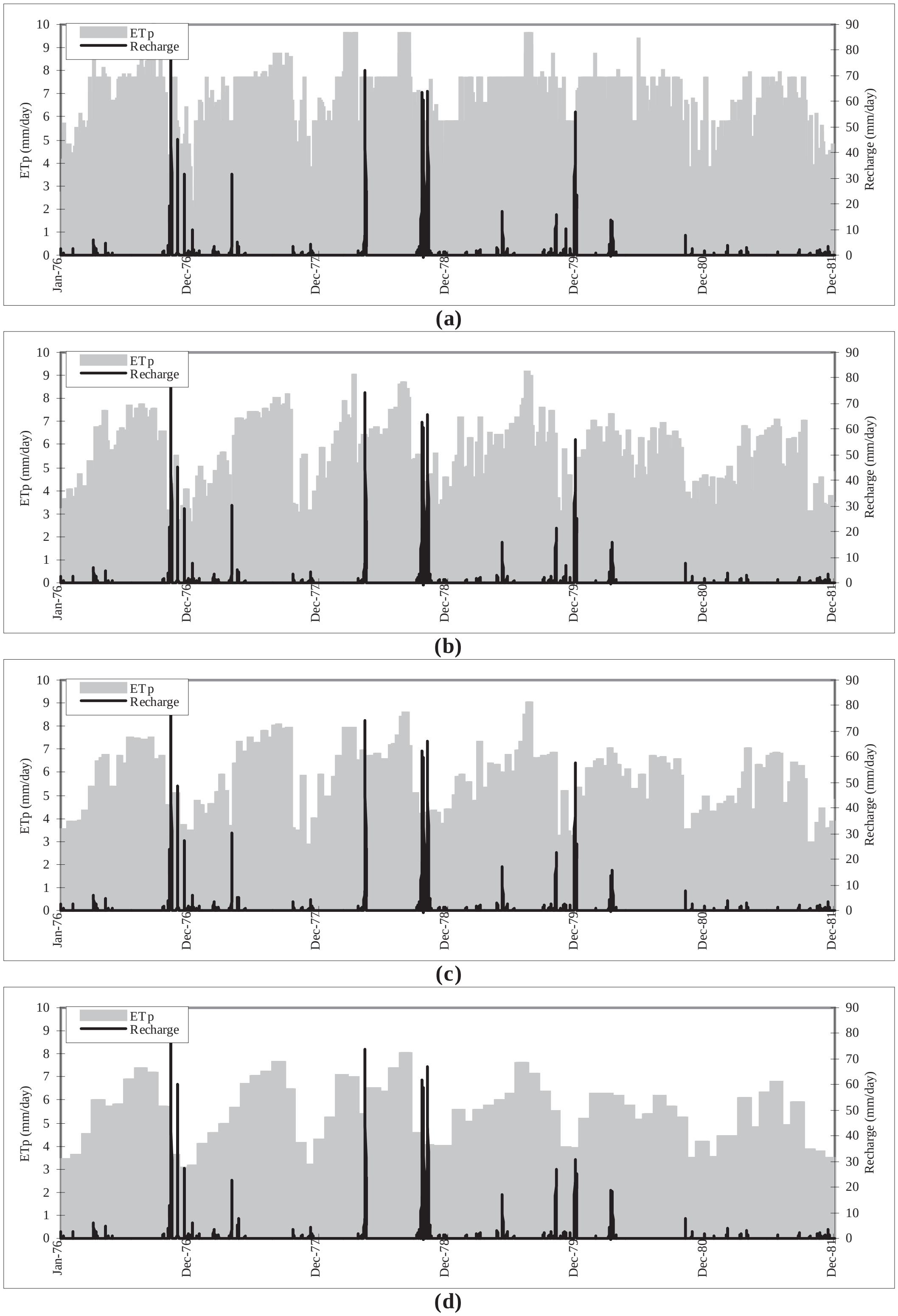

Figure 4. Potential evapotranspiration (ETp) and recharge estimated with four different ETp distributions for Kalpitiya from 1970-1975.

Table 10. Analysis of Variance Test Results for Comparing the Distributions of Recharge by Four Different ETp distributions at Maha Illuppallama

Source of Variation	Sum of squares	Degrees of freedom	Mean squares	F calc	F crit
Between Groups	0.25	3	0.08	0.007	2.60
Within Groups	105928.6	8764	12.08		
Total	105928.9	8767			

Table 11. Analysis of Variance Test Results for Comparing the Distributions of Recharge by Four Different ETp distributions at Kalpitiya

Source of Variation	Sum of squares	Degrees of freedom	Mean squares	F calc	F crit
Between Groups	0.44	3	0.14	0.008	2.60
Within Groups	152751.7	8764	17.42		
Total	152752.1	8767			

to daily data to estimate recharge in the dry zone of Sri Lanka with a soil water balance model. The resulting estimates of recharge will be very close to recharge estimates that use daily ETp data.

This finding has rather important practical applications, as in isolated remote villages of Sri Lanka it is likely that data is available only monthly or at most only weekly. Further, this study also suggests that sensitivity of pan evaporation data is very much less in estimating recharge with this method. Therefore, costly equipment may not be necessary to measure pan evaporation daily in the dry zone for the purpose of estimating recharge.

This study does not look into the effect of using distributed rainfall data. This, however, is likely to affect the results significantly as the daily variation of rainfall can be significant (from zero to 150 mm in the dry zone). Therefore distributing monthly rainfall evenly could result in the soil water balance predicting no recharge (or less recharge) when in fact there could be a significant recharge on heavy rainfall days.

A simplification was used by taking interception storage, runoff, and preferential flow threshold coefficients to be fixed values, as shown in Table 3. These values are the best available for interception of rainfall by vegetation, run off of rainfall and preferential flow. This simplification is not thought to affect the result significantly.

Abbreviations and Notation

The abbreviations and notations used in this paper are 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 coefficient
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 = Soil moisture deficit (mm)

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