A METHOD FOR THE ESTIMATION OF POTENTIAL EVAPOTRANSPIRATION AND/OR OPEN PAN EVAPORATION OVER BRAZIL[1]

S. JEEVANANDA REDDY[2] and MALAQUIAS DA SILVA AMORIM NETO[3]

ABSTRACT - This paper presents a simple regression model to estimate potential evapotranspiration and/or open pan evaporation data for a wide network of stations in Brazil. The model uses the readily available data sets like geocoordinates (latitude) and precipitation as inputs. Potential evapotranspiration presents a high correlation with the precipitation during summer months and with latitude during winter months. It also shows association with longitude and elevation; the magnitude of variation appears to be very small. This model gave a R^2 varying from 0.460 to 0.902 for different months. The model is also extended to weekly periods of individual years and tested with the open pan evaporation data of Bebedouro and Mandacaru. The agreement between observed and predicted values appears to be good.

Index terms: potential evapotranspiration, evaporation, precipitation, geocoordinates.

UM MÉTODO PARA ESTIMAR EVAPOTRANSPIRAÇÃO POTENCIAL E/OU EVAPORAÇÃO DO TANQUE NO BRASIL

RESUMO - Este trabalho apresenta um simple modelo de regressão para estimar dados de evapotranspiração potencial e/ou evaporação do tanque para rede de estações no Brasil. O modelo usa dados facilmente disponíveis nos locais, tais como coordenadas geográficas (latitude) e precipitação como entradas. A evapotranspiração potencial apresenta uma alta correlação com a precipitação durante os meses de verão e com a latitude durante os meses de inverno. Também mostra relação com a longitude e elevação; a magnitude de variação mostra-se muito pequena. Este modelo apresenta um R^2 variando de 0,460 a 0,902 para os diferentes meses. O modelo foi também aplicado para períodos semanais de anos individuais e testado com dados de evaporação do tanque de Bebedouro e Mandacaru. O ajustamento entre os dados observados e os estimados demonstra ser bom.

Termos para indexação: evapotranspiração potencial, evaporação, precipitação, coordenadas geográficas.

INTRODUCTION

The dry tropics are endowed with abundant energy. Temperature regimes are mostly favorable to crop growth throughout the year. However, these areas suffer from low and erratic rainfall. The rainfall is seasonal, variable from year to year and it is unevenly distributed within the rainy period. Therefore, considerable research effort is being devoted to understand the agrometeorology of the region. Such knowledge will be useful in the identification of periods of climatic water deficit or surplus for developing appropriate crop, soil and water management practices.

Of the different meteorological parameters - rainfall and evapotranspiration are of the special importance in the dry tropical environments. Both rainfall and potential evapotranspiration (or pan evaporation) are needed for the computation of climatic water balance in order to have a broad idea regarding the length of the growing season and its characteristics on one hand and crop(s) and their productivity in different regions, on the other hand. Extensive data base is available for precipitation. One of the serious limitations in the climatological analysis concerning regional crop planning is the paucity of potential evapotranspiration or pan evaporation data for large number of locations. Only at a few locations pan evaporation data are being recorded and that too in recent years. Also, only for a limited number of locations enough meteorological data are available to calculate the potential evapotranspiration through indirect approaches like Penman (1948) and this information collected over Brazil differs from the data collected over other parts of the world in terms of mode of recording.

Therefore, the objective of the present study is to evolve a sound technique for estimation of weekly potential evapotranspiration or pan evapora-

---

[1] Accepted for publication on January 11, 1984.

[2] Consultant (Agroclimatology), EMBRAPA - Centro de Pesquisa Agropecuária do Trópico Semi-Árido (CPATSA)/IICA, Caixa Postal 23 - CEP 56300 - Petrolina, PE.

[3] Engº - Agrº, (Agroclimatology), CPATSA/EMBRAPA.

tion using the data that are being used in the agroclimatic analysis, keeping in view the above mentioned limitations.

REVIEW OF THE PAST METHODS

Potential evapotranspiration is defined as the amount of water lost through transpiration by a short green sward fully covering the ground surface with unlimited water supply (Penman 1948). It is basically a parameter estimated from meteorological data. There are two important problems associated with the estimation of PE. Firstly, the identification of suitable method(s) for the estimation; and secondly, the availability of input data to the identified model.

The literature is replete with methods for the estimation of PE. These methods can be arranged into two categories, namely empirical and semi-empirical methods. Empirical methods define the simple regressions that relate PE with other meteorological parameters, selected arbitrarily. The major limitation of these techniques is that the constants derived from regression analysis are location-specific. These have limited application in global studies. A detailed listing of such methods is given by Reddy (1979a). The semi-empirical methods are derived by taking into account the physical processes involved and the constants are obtained by regression technique using the observed sets over time and space and hence these are termed semi-empirical methods (in literature they are grouped under physical models as their basic structure is based on physical concepts). They are the aerodynamic, the mass-transfer or eddy flux or correlation, the energy budget and the combination of both (Reddy 1979a). These techniques can be extended to other regions. However, they also have limitations, because the parameters used may not represent the entire physical process and sometimes regional or local effects dominate and modify the physical processes, e.g. advection, which is a major contributing factor to PE under dry conditions. Among these the most widely used method is the Penman (1948) combination approach. Penman (1948) gave the first physically sound treatment of the difficult problem of evaporation from a natural surface. The equation which he developed links evaporation rate to the net flux of radiant energy at the surface and to the effective ventilation of the surface by air motion over it; which means the combination of energy balance and aerodynamic terms into a single relationship. This approach is partly aesthetic and it promotes the understanding of the physical process of evaporation from natural surfaces; it requires meteorological information at one level only i.e. at 4' above ground level. However, in the Penman's equation that is currently in widespread use (see, e.g., Grindley 1970) there is a certain incompatability between the aerodynamic and energy balance terms (Thom & Oliver 1977). This has led many workers to suggest ways in which the Penman equation might be modified.

Following several tentative generalizations (cf. Penman & Schofield 1951, Penman 1956, 1961, Monteith 1965, 1973) a suggested modification to the aerodynamic term has been followed up by several workers (viz. Bavel 1966, McCaughey 1968, Thom et al. 1975). Thom & Oliver (1977) discussed its limitations in detail and they felt that there is no way in which it can be applied without some prior knowledge or appreciation of the size and nature of the surface term appropriate in each event.

Frere (1978) presented a manual for rapid computation of PE or E from the Penman (1948) equation as modified by Glover & McCulloch (1958).

Reddy & Rao (1973) verified the modified Penman (1948) method with actual open pan evaporation data collected at 30 locations in India (well distributed both in latitude and longitude) and found that it underestimated E at most stations. The deviations from observed values are high particularly during dry periods, i.e., this method does not account for high advection in the semi-arid tropics. They also suggested a simple empirical method (Reddy & Rao 1973, Reddy & Reddy 1973), but the weakness of this method is that the regression coefficients need to be verified for each continent as local factors that influence the energy balance differ significantly. In the past several publications appeared in the literature on the comparison of different methods for the estimation of pan evaporation or potential evapotranspiration (Stephens & Stewart 1963, Brutsaert 1965, Stanhill 1961, Papadakis 1977).

In addition to the above discussed limitations there is another important problem in the case of Brazil. That is, even the mode of recording the meteorological measurements like temperature and relative humidity are significantly different from other parts of the world, where the above discussed models are developed and tested. Therefore, before actually testing these models and applying to Brazil, it is important to correct or standardize the measured meteorogical data to internationally accepted standard. This will eventually take some time.

Under these circumstances, this problem needs to be attempted in a different direction. Reddy & Virmani (1980) estimated potential evapotranspiration using geocoordinates for about 350 locations over West Africa. Similar approach is one such possibility. Hargreaves (1977) computed potential evapotranspiration for entire globe which includes 31 locations from Brazil. Hargreaves also computed potential evapotranspiration for entire northeast Brazil on monthly basis some based on his model and some by extrapolation (Hargreaves 1974). Hargreaves (1977) derived potential evapotranspiration (PE') using the following empirical equation:

$$PE' = MF \times TF \times CH \qquad (1)$$

in which

MF = 0.00483 x RMM x DL/12 x CL
TF = mean temperature in degrees fahrenheit
CH = a coefficient for mean relative humidity

where

RMM = extraterrestrial radiation expressed as equivalent mm of evaporation per month
DL = day length in hours
CL = $0.17 \times (70 - ABL)^{1/2}$ with a maximum value of 1.00 & ABL - absolute value of the latitude
TF = $-32 + 1.8 \times T$
T = $(T_{1200} + 2\,T_{2400} + T_{mx} + T_{mi})/5$

with T_{1200}, T_{2400}, T_{mx} & T_{mi} representing temperature recorded at 1200 & 2400 hours, maximum & minimum.

CH = $0.158\,(100 - U)^{1/2}$ with a maximum value of 1.00

The input data are available at only 154 locations over northeast Brazil (Hargreaves 1974). It was, therefore, first attempted to check these estimates with pan evaporation data published for Norhteast Brasil (Brasil. SUDENE 1973). The open pan evaporation data over Northeast Brazil represents the data of mesh uncovered condition. The open pan evaporation with mesh cover is equivalent to 0.87 times the open pan evaporation with mesh uncovered (Stanhill 1962, Campbell & Phene 1976, Pruitt 1966, Silva et al. 1981). The potential evapotranspiration is equivalent to 0.85 times open pan evaporation with mesh covered (Reddy 1979b). Then potential evapotranspiration (PE') values computed using Hargreaves (1977) method can be converted to open pan evaporation (mesh uncovered) as:

$$E' = PE'/(0.87 \times 0.85) \qquad (2)$$

Table 1 presents the deviations (D = E - E') of estimated open pan evaporation values (E') from the observed open pan evaporation (E) at ten locations over northeast Brazil. It is seen from this table that the deviations are positive during March to May; and negative during June to January with few exceptions.

Two reasons can be speculated for this type of deviations:

i. difference in the estimates of temperature and relative humidity; and
ii. method of estimating PE'

- In any case, as the deviations are quite uniform, it is simple to suggest an appropriate correction factor.

This is given as:

$$PE = PE' \times K_i \qquad (3)$$

where PE' is the Hargreaves estimates using eq. 1 and K_i is the correction factor, which varies with seasons as:

$$K_i = 1 + 0.15 \cos\left(\frac{2\pi}{12}\, i - 300\right) \qquad (4)$$

where i = 1 to 12 for January to December.

Table 2 presents the percentage deviations during January to December at ten locations over northeast Brazil along with the percentage locations the deviations are below, 5, 10, 15, 20 and 25% of observed values.

TABLE. 1. Comparison of open pan evaporation data with the estimates of pan evaporation through potential evapotranspiration at few selected locations over northeast Brazil.

Locations	Lat. (degrees)	Long. (degrees)	Elev. (m)	Deviations* in mm											
				1**	2	3	4	5	6	7	8	9	10	11	12
1. Sobral	03.70	40.35	075	-1	3	47	60	53	43	7	-25	-5	-29	-13	-12
2. Quixeramobim	05.18	39.30	187	-8	-1	40	50	52	30	11	-45	-54	-55	-27	-45
3. Crateús	05.18	40.67	275	-17	-5	29	45	37	4	-22	-29	-35	-41	-40	-45
4. Florânia	06.12	36.82	210	-30	-17	26	34	25	8	-15	-39	-31	-31	-40	-52
5. Campos Sales	07.05	40.38	551	12	29	51	43	15	-6	-6	-64	-22	-37	-33	-9
6. Picos	07.07	41.47	195	-2	18	40	58	9	-22	-51	-60	-68	-61	-36	-29
7. Cabrobó	08.52	39.32	350	-19	-3	29	29	7	-14	-18	-36	-57	-52	-55	-67
8. Bebedouro	09.08	40.33	350	-10	7	29	49	31	5	-7	-23	-32	-30	-4	12
9. Remanso	09.67	42.07	378	-31	-4	4	31	0	-24	-39	-34	-49	-58	-19	-40
10. Barra	11.08	43.15	410	-18	-20	-7	30	-6	-22	-38	-45	-81	-23	-12	-10

* Deviations = Estimated pan evaporation from potential evapotranspiration using Eq. 16 - observed open pan (U.S. Class 'A') evaporation.

** 1 to 12 respectively represent January to December.

TABELA 2. Percentage deviations of estimated pan evaporation from observed pan evaporation over northeast Brazil.

Location	Percentage deviations											
	1*	2	3	4	5	6	7	8	9	10	11	12
Sobral	- 00	- 08	07	15	14	16	00	24	25	19	11	05
Quixeramobim	- 03	- 11	02	06	13	07	02	09	05	08	06	- 03
Crateús	- 07	- 13	- 03	04	02	- 08	- 13	03	04	04	01	- 07
Florânia	- 11	- 18	- 05	- 04	- 05	- 06	- 07	- 05	- 04	- 07	- 01	- 09
Campos Sales	06	06	10	02	- 10	- 13	- 07	02	14	07	02	06
Picos	- 10	00	03	09	- 13	- 18	- 20	- 15	- 07	- 08	01	- 03
Cabrobó	- 08	- 11	- 05	- 08	- 14	- 17	- 09	- 05	- 05	- 00	- 05	- 16
Bebedouro	- 04	- 11	- 05	05	- 03	- 08	- 03	00	01	08	15	17
Remanso	- 12	- 12	- 13	- 07	- 17	- 23	- 21	- 03	- 02	- 02	08	- 08
Barra	- 08	- 18	- 15	- 07	- 24	- 20	- 17	- 05	- 13	- 09	11	05
< 05	40	10	60	40	30	00	30	70	60	30	50	40
< 10	80	30	80	90	40	40	60	80	70	90	70	80
< 15	100	80	100	100	80	50	70	90	90	90	100	80
< 20	-	100	-	-	90	90	90	90	90	100	-	100
< 25	-	-	-	-	100	100	100	100	100	-	-	-

* 1 to 12 respectively represent January to December.

However, the deviations, still, appear to be higher. There is one important major problem with measured open pan evaporation data to use them directly in regression analysis. That is, abnormal differences in the data sets of nearby locations. See, for example, Florânia and Bebedouro. The energy received on unit area during December and January at Bebedouro are about 550-600 ly/day while they are about 450-500 ly/day at Florânia (Vieiro et al. 1981). The difference is about 100 ly/day (equivalent to about 1.5 mm/day - Penman 1948). Except that the precipitation is slightly higher at Bebedouro compared to Florânia while relative humidity is higher at Florânia. Under such circumstances even with a severe advection it may not be possible to explain high variation such as: 0.4 mm per unit of energy recorded at Bebedouro while it is 0.6 mm per unit energy received at Florânia. This may be a localized effect than a representative of that region.

SUGGESTED PROCEDURE FOR THE ESTIMATION OF POTENTIAL EVAPOTRANSPIRATION OVER BRAZIL

To estimate potential evapotranspiration the study was divided into two parts:

i. To develop an appropriate equation that uses readily available parameters like geocoordinates and precipitation for the estimation of average monthly potential evapotranspiration; and
ii. To develop a suitable method for the computation of weekley potential evapotranspiration for individual years.

To achieve this goal a multiple regression approach was followed. The basic potential evapotranspiration data used in this study were the potential evapotranspiration estimates of Hargreaves (1977) for 31 locations (Fig. 1) over Brazil distributed uniformly covering all possible climates.

In any agroclimatic analysis the parameter invariably present is precipitation[4] (R). The other easily and readily available information for any location are latitude (la), longitude (lo) and elevation (e). These are indirectly related to energy distribution; land-sea contrast etc. Therefore, PE' was regressed with these four parameters.

REGRESSION ANALYSIS RESULTS

A) PE' vs R, R_{-1}, la, lo & e:

A multiple linear regression of the form:

$$PE' = a + b_1 \times la + b_2 \times lo + b_3 \times e + + b_4 \times R + b_5 \times R_{-1} \qquad (5)$$

was fitted to the data of 31 locations (Fig. 1); where la & lo are in degrees, e is in meters and R & R_{-1} are in mm. Table 3 presents the regression parameters and their respective standard errors;

---

[4] R indirectly present the cloud cover & vapour pressure or relative humidity situation of the atmosphere.

FIG. 1. Locator map.

levels of significance along with R^2 for each of the 12 months January to December.

i. The effect of latitude (b_1) appears to be significant during March to October. That is, when the sun is in the Northern Hemisphere the PE decreases with increasing latitude significantly. When the sun is in the Southern Hemisphere this pattern disappears, i.e., during November to February. The regression parameters vary from January to December in a cosine form.

ii. When the sun is in the northern hemisphere, PE' also appears to decrease with increasing longitude (b_2) significantly, particularly during April to July.

iii. The PE' decreases with increasing elevation (b_3). However, only few of these parameters are statistically significant. This may be due to low range of elevation of which this data set comprise off (< 1.000 m).

iv. The PE' decreases with increasing precipita-

TABELA 3. Regression parameters and their significance (using five independent variables). Eq. 5.

Months	$	Regression parameters*						
		a	b_1	b_2	b_3	b_4	b_5	R^2
January	1	202.8	0.691**	-.401	-.019***	-.199*	0.046	0.764
	2		.29	.34	.010	.05	.05	
February	1	180.7	-0.180	-	-.010	-.203*	-	0.805
	2		.23	-	.007	.02	-	
March	1	220.7	-1.304*	-.313	-.007	-.097**	-.129*	0.806
	2		.29	.29	.008	.05	.05	
April	1	245.6	-2.661*	-.773*	.028*	-.181*	-.034	0.829
	2		.27	.21	.009	.04	.03	
May	1	229.7	-3.404*	-.703*	-.023*	-.045	-.115*	0.888
	2		.26	.21	.008	.03	.03	
June	1	202.4	-3.539*	-.638*	-.013	-	-.091*	0.904
	2		.23	.21	.008	-	.02	
July	1	198.4	-3.619*	-.455***	-.009	-	-.082*	0,893
	2		.25	.24	.008	-	.03	
August	1	211.2	-3.279*	-.353	-.010	-.197*	-	0.889
	2		.26	.24	.009	.05	-	
September	1	201.2	-2.486*	-	-.013	-.311*	-	0.885
	2		.26	-	.008	.05	-	
October	1	208.1	-1.348*	-	-.022***	-.125***	-.187***	0.696
	2		.37	-	.010	.07	.11	
November	1	188.3	-	-	-.025**	-.040	-.194*	0.591
	2		-	-	-.010	.06	.07	
December	1	203.2	0.490	-.379	-.012	-.171*	-	0.649
	2		.33	.35	.01	.04	-	

$: 1 = regression parameters;
2 = standard errors of regression parameters
* = significant at > 99%
** = significant at > 95%
*** = significant at > 90%

tion amount (b_4) during August to April (excluding November). However, the months in which the precipitation is not significantly correlated with PE', the antecedent precipitation parameter (b_5) is significantly related to PE', i.e., the PE' decreases with the increase in anticedent (previous months) precipitation amount during May to July & November.

B) PE' vs $R^{0.25}$, $R_{-1}^{0.25}$, la, lo & e:

To understand the ability to improve the predictions in Eq. 5, the parameters of precipitation (R & R_{-1}) were converted to curvilinear forms. - After trying forms of curviliniarity like log, exp and power functions, it was found that $R^{0.25}$ is a better fit. Hence the eq. 5 was modified as:

$$PE' = a + b_1 \times la + b_2 \times lo + b_3 \times e + b_4 \times R^{0.25} + b_5 \times R_{-1}^{0.25} \qquad (6)$$

This was also fitted to the same data set as mentioned above. Table 4 presents the regression parameters and their respective standard errors and levels of significance along with R^2 for each of the 12 months January to December.

TABELA 4. Regression parameters and their significance (using five independent variables). Eq. 6.

Months	$	Regression parameters*						
		a	b_1	b_2	b_3	b_4	b_5	R^2
January	1	271.1	0.886*	-.295	-.014	-29.823*	-	0.757
	2		.28	.35	.009	5.83	-	
February	1	278.0	-	-	-.008	-38.307*	-	0.828
	2		-	-	.006	3.39	-	
March	1	353.2	-1.297*	-.338	-.006	-26.257**	-21.771**	0.816
	2		.29	.30	.008	11.20	9.90	
April	1	370.6	-2.690*	-.694*	-.031*	-33.175*	-13.238***	0.842
	2		.27	.20	.009	6.69	6.57	
May	1	296.0	-3.246*	-.623*	-.028*	-7.946**	-20.345*	0.893
	2		.25	.20	.008	3.91	6.84	
June	1	209.8	-3.175*	-.533*	-.014**	-10.655*	-	0.922
	2		.20	.19	.007	2.17	-	
July	1	219.6	-3.465*	-.385***	-.017**	-	-11.823*	0.926
	2		.20	.20	.007	-	2.30	
August	1	239.9	-3.108*	-.281	-.018*	-17.859*	-	0.931
	2		.21	.19	.007	2.65	-	
September	1	257.6	-2.503*	-.214	-.019**	-16.680**	-7.855***	0.916
	2		.24	.27	.007	6.41	4.02	
October	1	265.0	-1.179*	-	-.026**	-10.867	-18.684**	0.739
	2		.34	-	.010	6.63	8.02	
November	1	240.1	-	-	-.027*	-	-25.245*	0.668
	2		-	-	.008	-	3.88	
December	1	256.6	0.662***	-	-.012	-29.738*	-	0.651
	2		.32	-	.010	4.97	-	

$: 1 = regression parameters;
2 = standard errors of regression parameters
* = significant at > 99%
** = significant at > 95%
*** = significant at > 90%

On each count, in majority of the parameters the significance is improved in Table 4 compared to Table 3 (the standard errors of individual parameters are lower in Table 4 compared to Table 3) with the general pattern being similar in both the tables. R^2 values are slightly improved in Table 4 compared to Table 3. It can now be inferred that the predictive ability of Eq. 6 is better than Eq. 5.

C) PE' vs $R^{0.25}$, $R_{-1}^{0.25}$, la & e:

Multiple regression was carried out by deleting longitude parameter in Eq. 6, i.e.

$$PE' = a + b_1 \times la + b_2 \times e + b_3 \times R^{0.25} + \\ + b_4 - R_{-1}^{0.25} \qquad (7)$$

Table 5 presents the results.

On comparison between Tables 4 and 5, it was observed that: R^2 values are slightly lower in Table

TABLE 5. Regression parameters and their significance (using four independent variables). Eq. 7.

Months	$	Regression parameters*				
		a	b_1	b_2	b_3	b_4	R^2
January	1	267.8	0.867*	-.012	-33.107*	-	0.750
	2		.28	.009	4.31	-	
February	1	278.1	-	-.008	-38.307*	-	0.828
	2		-	.006	3.39	-	
March	1	338.4	-1.261*	-	-19.266**	-30.051*	0.806
	2		.29	-	9.18	6.72	
April	1	351.0	-2.791*	-.027**	-31.773*	-18.399**	0.765
	2		.32	.010	7.97	7.64	
May	1	270.9	-3.281*	-.027	- 6.513	-23.213*	0.850
	2		.29	.010	4.50	7.86	
June	1	181.8	-3.161*	-.012	-10.297*	-	0.897
	2		.22	.008	2.44	-	
July	1	203.2	-3.538	-.017	11.033	-22.767**	0.921
	2		.22	.008	8.08	8.54	
August	1	227.9	-2.992*	-.018**	-28.534*	8.945	0.930
	2		.22	.007	7.87	6.28	
September	1	251.8	-2.440*	-.019**	-20.116*	- 6.349	0.913
	2		.23	.007	4.73	3.53	
October	1	265.0	-1.179*	-.026**	-10.867	-18.684**	0.739
	2		.34	.001	6.63	8.02	
November	1	240.1	-	-.027*	-	-25.245*	0.668
	2		-	.008	-	3.88	
December	1	256.6	0.662**	-.012	-29.738*	-	0.651
	2		.32	.011	4.97	-	

$: 1 = regression parameters; 2 = standard errors of regression parameters

* = significant at > 99%

** = significant at > 95%

*** = significant at > 90%

5 compared to Table 4 in few months; also standard errors of few parameters are significantly large in Table 5 compared to Table 4 during January, September and December.

D) PE' vs $R^{0.25}$, la, lo & e:

Multiple regression was also carried out by deleting R_{-1} parameter in Eq. 6, i.e.

$$PE' = a + b_1 \times la + b_2 \times lo + b_3 \times e + b_4 \times R^{0.25} \quad (8)$$

The results are presented in Table 6. It is seen from this table that the standard errors associated with R are slightly lower than those in Table 4 and also most of the parameters associated with R (b_3) are statistically significant but it is surprising to note that R^2 has come down in some months, particularly in March and November.

It was not attempted to see whether there is any improvement in Eq. 8 by eliminating e, as the contribution of this parameter is only of the order of 10 mm for 1.000 m elevation (Table 4).

Therefore, from the above results it can be inferred that the better solution to estimate PE'

TABLE 6. Regression parameters and their significance (using three independent variables). Eq. 8.

Months	$	Regression parameters*				
		a	b_1	b_2	b_3	R^2
January	1	267.8	0.867*	-.012	-33.102*	0.750
	2		0.28	.009	4.31	
February	1	278.1	-	-.008	-38.307*	0.828
	2		-	.006	3.39	
March	1	362.0	-1.627*	-.013	-52.484*	0.689
	2		.35	.009	6.94	
April	1	319.8	-2.521*	-.037*	-42.655*	0.713
	2		.32	.010	7.13	
May	1	204.4	-2.808*	-.018	-14.141*	0.799
	2		.28	.010	4.18	
June	1	181.8	-3.161*	-.012	-10.297*	0.897
	2		.22	.008	2.44	
July	1	190.5	-3.386*	-.011	- 9.655*	0.900
	2		.24	.008	2.49	
August	1	226.0	-3.098*	-.017**	-17.971*	0.925
	2		.21	.007	2.70	
September	1	249.0	-2.421*	-.014**	-25.419*	0.903
	2		.24	.007	3.85	
October	1	249.2	-1.433*	-.012	-22.188*	0.684
	2		.35	.010	4.87	
November	1	228.7	-2.238	-.013	-20.447*	0.504
	2		.34	.010	4.94	
December	1	256.6	0.662	-.012	-29.738*	0.652
	2		.32	.010	4.97	

$: 1 = regression parameters; 2 = standard errors of regression parameters

* = significant at > 99%

** = significant at > 95%

*** = significant at > 90%

over Brazil is Eq. 6 with the parameters presented in Table 4.

Fig. 2 presents the scatter of observed vs predicted PE' values during January to December using Eq. 5. Fig. 3 presents the spatial distribution of predicted deviations from observed PE' for January to December using Eq. 2. It appears from these figures that the deviations are not uniform but present random variations. Only at one location the deviations during November to January are considerably large (Remanso).

However, the regression coefficients in Table 4, particularly that of precipitation (b_4) show ambiguity during certain periods. That is, in the case of July and November, even when there is precipitation, it is not going to effect the evaporation, which is not true.

Therefore, it was felt that it may be appropriate to combine both precipitation of the month and the antecedent precipitation of the previous month. For this purpose the form that was employed by Reddy (1979b) was used. This is given as:

$$R' = (R + (1/3)\ R_{-1})^{1/3};$$

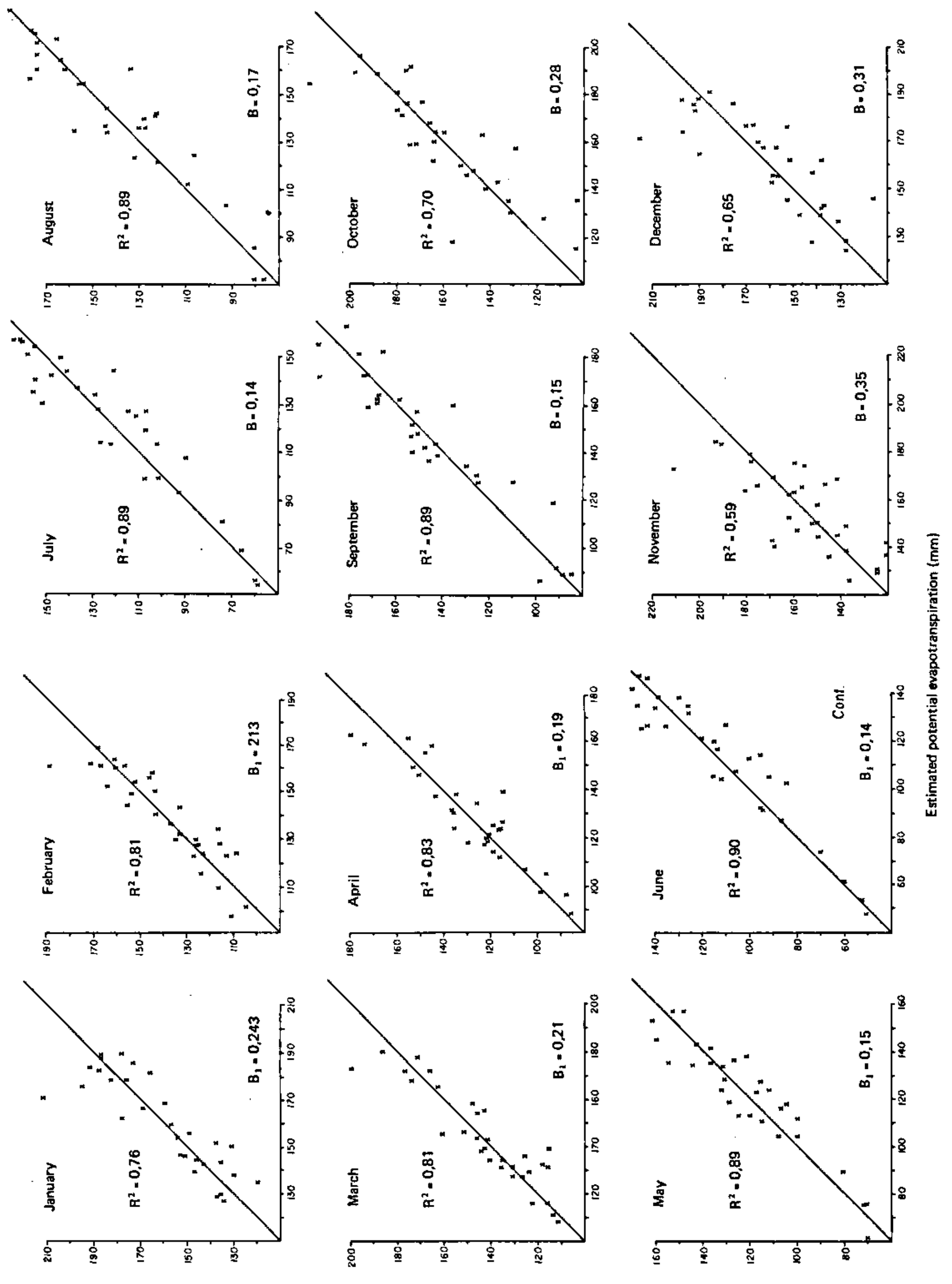
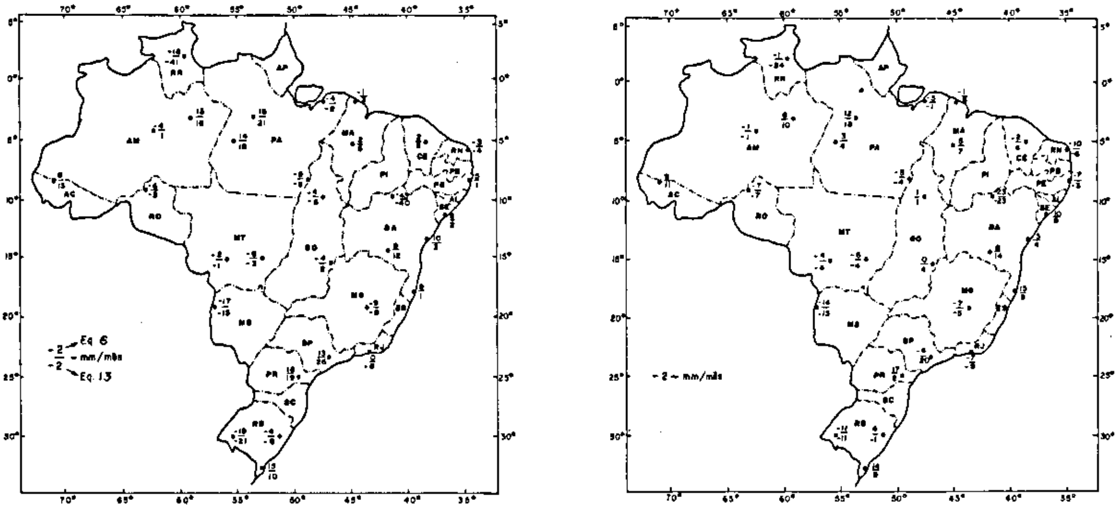
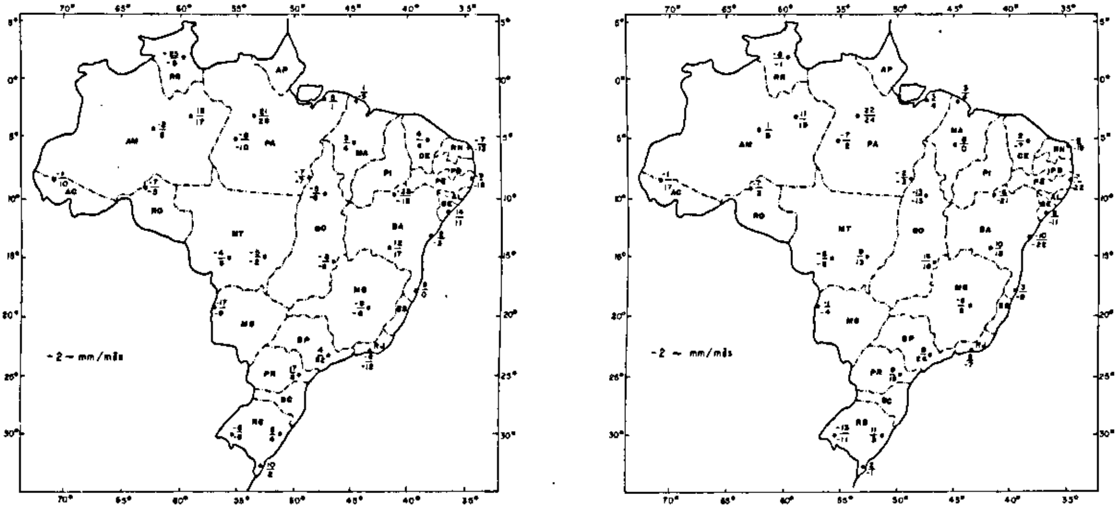


FIG. 2. Comparison of observed and estimated (using equation 5) potential evapotranspiration.



January

February

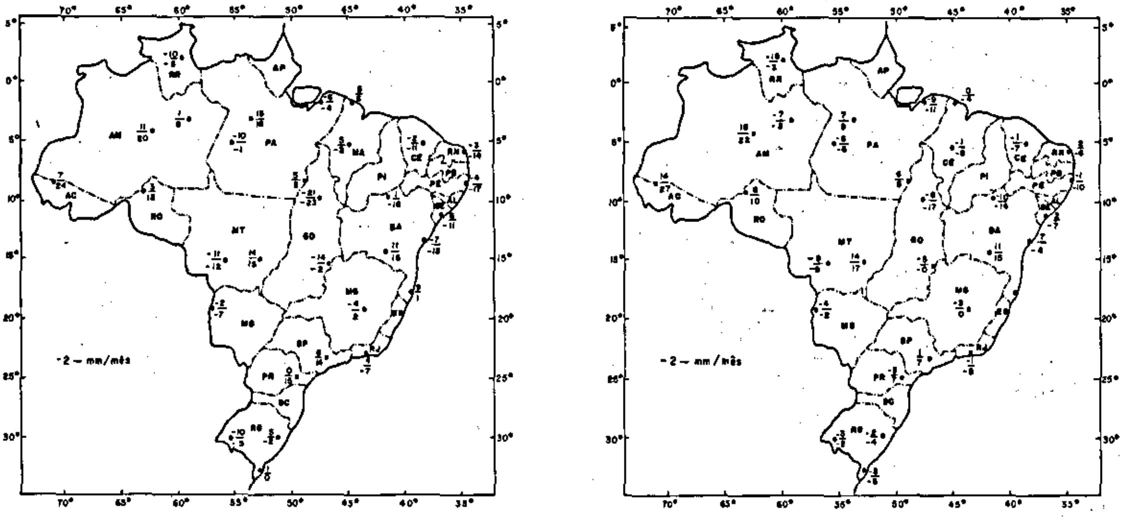


March

April

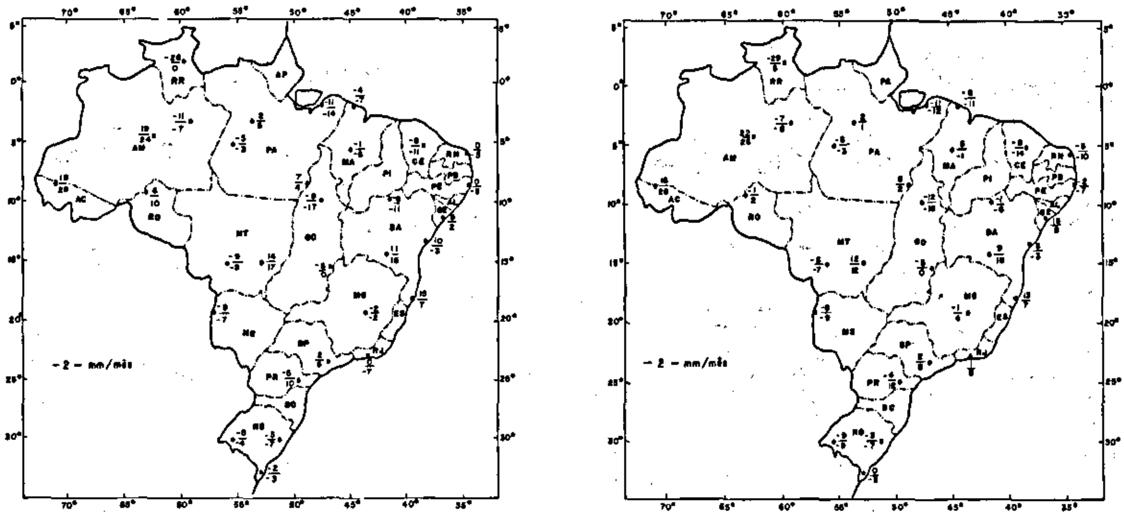
Cont.

FIG. 3. Spatial distribution of the deviations of estimated (using equations 6 & 13) potential evapotranspiration from observed over Brazil.



May

June

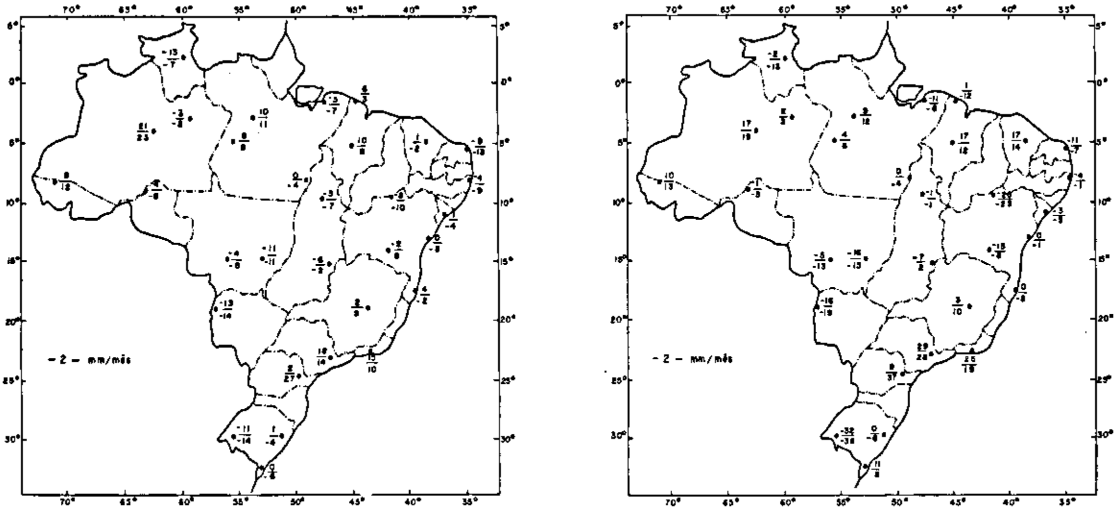


July

August

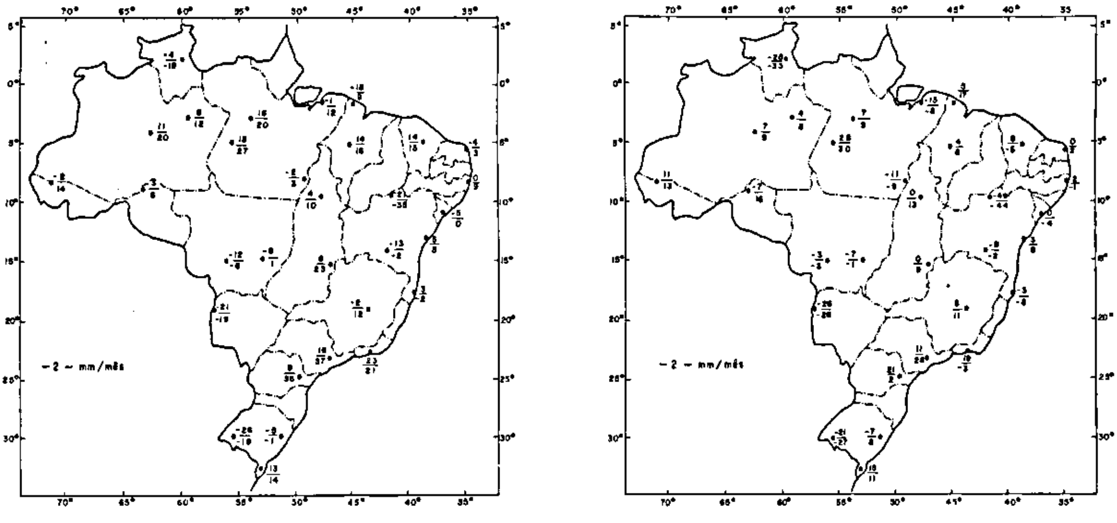
Cont.

FIG. 3. (Cont.) Spatial distribution of the deviations of estimated (using equations 6 & 13) potential evapotranspiration from observed over Brazil.



September

October



November

December

FIG. 3. (Cont.) Spatial distribution of the deviations of estimated (using equations 6 & 13) potential evapotranspiration from observed over Brazil.

with this modification again the following four forms were tried:

$$PE' = a + b_1 \ x \ la + b_2 \ x \ lo + b_3 \ x \ l + b_4 \ x \ R' \quad . \ (10)$$

$$PE' = a + b_1 \ x \ la + b_2 \ x \ lo + b_3 \ x \ R' \quad ..(11)$$

$$PE' = a + b_1 \ x \ la + b_2 \ x \ e + b_3 \ x \ R' \quad ..(12)$$

$$PE' = a + b_1 \ x \ la + b_2 \ x \ R' \quad ..(13)$$

Tables 7 to 10 present the regression coefficients for the above four equations respectively in order.

During April to September the R^2 values are superior with Eq. 10 while they are superior with Eq. 6 during October to March (Table 4 &7). In general, R^2 values are better in Table 7 (Eq. 10) compared to Tables 8-10 (Eqs. 11-13). However, the differences are not substantially large.

On comparison the deviations from observed at all the 31 locations do not show much difference either with equation 6 or 10 on one hand and Eqs. 10 or 11 or 12 or 13 on the other hand.

TABLE 7. Regression parameters and their significance (using four independent variables). Eq. 10.

Months	$	Regression parameters*					
		a	b_1	b_2	b_3	b_4	R^2
January	1	239.2*	.791	-.354	-.015	-11.545*	0.649*
	2	17.1	.35	.48	.01	3.6	
February	1	240.0*	- .202	.230	-.007	-17.589*	0.738*
	2	14.5	.28	.21	.01	2.36	
March	1	337.2*	-1.666*	-.382	-.010	-23.932*	0.793*
	2	19.8	.30	.75	.01	2.97	
April	1	322.8*	-2.561*	-.802	-.028*	-19.104*	0.843*
	2	19.6	.25	.19	.01	2.43	
May	1	263.9*	-2.988*	-.830*	-.028*	-10.888*	9.914*
	2	14.8	.19	.17	.01	1.61	
June	1	219.9*	-3.191*	-.656*	-.019*	-7.035*	0.938*
	2	11.5	.17	.17	.01	1.15	
July	1	224.0*	-3.341*	-.609*	-.019**	-6.726*	0.934*
	2	12.5	.20	.19	.01	1.17	
August	1	242.2*	-3.082*	-.481**	-.021*	-9.620*	0.935*
	2	11.8	.20	.19	.01	1.36	
September	1	245.3*	-2.417*	-.163	-.019**	-13.592*	0.918*
	2	10.9	.23	.21	.01	2.12	
October	1	241.4*	-1.428*	-.031	-.016	-11.970*	0.699*
	2	16.6	.36	.43	.01	3.55	
November	1	234.2*	- .339	-.261	-.018	- 8.678**	0.512*
	2	17.4	.35	.43	.01	3.19	
December	1	232.6*	0.547	-.237	-.019	-10.996*	0.586*
	2	17.3	.36	.42	.01	3.32	

$: 1 = regression parameters; 2 = standard errors of regression parameters

* = significant at > 99%

** = significant at > 95%

*** = significant at > 90%

These deviations for Eq. 13 are also depicted in Figure 3 along with Eq. 6.

On comparison of Tables 6 and 9, it appears that in majority of the months the R^2 values are slightly higher with Eq. 12 compared to Eq. 8 with the same three independent variables (latitude, elevation and precipitation).

Therefore, when elevation is not an important variable Eq. 13 or when elevation is also an important variable Eq. 12 can be used for the estimation of potential evapotranspiration or pan evaporation on monthly basis. In the case of northeast Brazil where the terrain is more or less uniform (less than 1.000 m), Eq. 13 can be used for the estimation of potential evapotranspiration or pan evaporation.

EXTENSION OF THE MODEL TO CALCULATE WEEKLY PE' DATA

1. Let us consider Eq. 13, the simplest function:

$$PE' = a + b_1 \, la + b_2 \, (R + R_{-1}/3)^{1/3}$$

Where a, b_1 and b_2 are presented in Table 10.

TABLE 8. Regression parameters and their significance (using three independent variables). Eq. 11.

Months	$	Regression parameters*				
		a	b_1	b_2	b_3	R^2
January	1	239,0*	0.625**	-.101	-13.770*	0.626*
	2	17.4	.33	.44	.02	
February	1	241.4*	- .293	.258	-18.108*	0.731
	2	14.3	.26	.20	2.27	
March	1	336.6*	-1.782*	-.340	-24.281*	0.777*
	2	20.1	.29	.25	3.01	
April	1	285.5*	-2.495*	-.765*	-14.468*	0.748*
	2	21.3	.30	.24	2.65	
May	1	230.7*	-3.012*	-.717*	- 6.873*	0.863*
	2	15.1	.24	.21	1.55	
June	1	203.7*	-3.313*	-.569*	- 5.042*	0.917*
	2	11.6	.19	.19	1.07	
July	1	209.6*	-3.502*	-.900**	- 5.046*	0.917*
	2	12.5	.21	.21	1.10	
August	1	228.2*	-3.295*	-.403**	- 7.462*	0.914*
	2	12.1	.21	.21	1.28	
September	1	236.3*	-2.689*	-.233	-10.794*	0.895*
	2	11.6	.23	.23	2.06	
October	1	237.4*	-1.592*	-.012	-11.648*	0.670*
	2	16.9	.35	.44	3.64	
November	1	231.5*	- .472	-.055	-10.513*	0.462*
	2	17.8	.35	.42	3.07	
December	1	232.8*	.383	-.003	-13.405*	0.550*
	2	17.6	.35	.40	2.97	

$: 1 = regression parameters; 2 = standard errors of regression parameters

* = significant at > 99%

** = significant at > 95%

*** = significant at > 90%

TABLE 9. Regression parameters and their significance (using three independent variables). Eq. 12.

Months	$	Regression parameters*				
		a	b_1	b_2	b_3	R^2
January	1	233.8*	0.743*	-.011	-13.575*	0.641*
	2	15.4	.34	.01	2.4	
February	1	242.7*	- .104	-.008	-16.393*	0.726*
	2	14.3	.27	.01	2.11	
March	1	332.0*	-1.782*	-.009	-25.917*	0.773*
	2	20.0	.030	.01	2.75	
April	1	287.4*	-2.583*	-.026	-19.818*	0.735*
	2	22.5	.31	.01	3.09	
May	1	214.7*	-2.928*	-.022*	- 9.741*	0.838*
	2	14.3	.26	.01	2.14	
June	1	182.6*	-3.174*	-.015***	- 6.258	0.902*
	2	8.1	.22	.01	1.41	
July	1	188.9*	-3.346*	-.014***	- 5.762*	0.909*
	2	6.8	.23	.01	1.31	
August	1	216.1:	-3.085*	-.018**	- 9.181*	0.918*
	2	6.8	.22	.01	1.49	
September	1	239.8*	-2.382*	-.020*	-14.262*	0.916*
	2	8.2	.22	.01	1.92	
October	1	240.6*	-1.422*	-.016	-12.144*	0.699*
	2	12.5	.34	.01	2.52	
November	1	217.4*	- .322	-.016	- 9.943*	0.505*
	2	13.2	.34	.01	2.39	
December	1	227.6*	.534	-.016	-12.234*	0.581*
	2	14.6	.36	.01	2.44	

$: 1 = regression parameters; 2 = standard errors of regression parameters

* = significant at > 99%

** = significant at > 95%

*** = significant at > 90%

TABLE 10. Regression parameters and their significance (using two independent variables). Eq. 13.

Months	$	Regression parameters*			
		a	b_1	b_2	R^2
January	1	237.1*	0.621**	-14.286*	0.625*
	2	15.1	.32	2.28	
February	1	244.9*	- .202	-16.853*	0.715*
	2	14.2	.26	2.07	
March	1	332.0*	-1.873*	-26.033*	0.761*
	2	20.1	.26	2.77	

TABLE 10. Continuation.

Months	$	Regression parameters*			
		a	b_1	b_2	R^2
April	1	253.6*	2.519*	-15.382*	0.650*
	2	21.9	.35	3.05	
May	1	192.8*	-2.954*	- 6.576*	0.804*
	2	11.9	.28	1.81	
June	1	173.6*	-3.273*	- 4.756*	0.889*
	2	6.9	.22	1.21	
July	1	182.6*	-3.471*	- 4.588*	0.898*
	2	6.0	.23	1.17	
August	1	207.5*	-3.274*	- 7.327*	0.902*
	2	6.0	.22	1.34	
September	1	227.8*	-2.651*	-11.627*	0.891*
	2	7.9	.22	1.89	
October	1	237.1*	-1.590*	-11.716*	0.670*
	2	12.6	.33	2.58	
November	1	220.0*	- .467	-10.758*	0.462*
	2	13.4	.35	2.39	
December	1	232.7*	.383	-13.420*	0.550*
	2	14.4	.35	2.33	

$: 1 = regression parameters; 2 = standard errors of regression parameters

* = significant at > 99%

** = significant at > 95%

*** = significant at > 90%

2. Using the analogy presented in Eq. 3, multiply all the three regression coefficients a, b_1 & b_2 by K_i (Eq. 4).
3. The regression coefficients a, b_1 & b_2 represent for total days in a month. In order to convert these to daily values, divide regression coefficients by number of days in the respective months. To represent these coefficients for weekly interval, multiply coefficients by the number of days in respective weeks (generally 7, except for week 52 & week number 9 in leap year it is 8).
4. Multiply the precipitation amount $(R + R_{-1}/3)$ by a factor Z obtained as a ratio of number of days in a month/number of days in a week. When a week comprises of days from two months, then it is the sum of this ratio multiplied by their respective days in each month i.e.

$$Z_i = a_1 \frac{M_1}{W} + a_2 \frac{M_2}{W} \quad ..(14)$$

Where $a_1 = 1 - a_2$ & $a_1 = x/W$ with x being number of days from month M_1. When x = then $a_2 = 0$ and $a_1 = 1$. W is the number of days in a week and M_1 or M_2 or number of days in a month 1 or 2 etc.

This correction is essential because the regression coefficients were derived based on precipitation totals and not based on average monthly values.

5. By considering each of the regression coefficient (a, b_1 & b_2) representing the middle

of the respective months, linearly interpolate for each of the standard weeks (representing for the middle of the weeks).

6. Then compute PE using above mentioned equation. Also, E can be estimated using Eq. 2 as:
   E = PE/(0.85 x 0.87) for mesh uncovered or
   E = PE/0. 85 (for mesh covered).

Test the validity of this approach:

For testing the validity of this approach the pan evaporation data of Bebedouro and Mandacaru for five years each were considered. Fig. 4 & 5 respectively depict the observed VS predicted pan evaporation (mesh uncovered) for Bebedouro and Mandacaru. In the case of Bebedouro the correlation between observed and predicted open pan evaporation values are of the order of 0.77-0.89 during 1968, 1971, 1978 & 1982 while it is slightly lower for 1976. In the case of Mandacaru these values are of the order of 0.69-0.83.

It is seen from Fig. 4 and 5, that majority of the estimated values are above the 1:1 line for Mandacaru; while it is opposite for Bebedouro. That is, in majority of the cases the estimated values are more than obseved values for Bebedouro while they are less than observed values for Mandacaru. This can also be seen in overall averages (but not in standard deviations):

Locations	Pan evaporation*mm	
	Observed	Estimated
Mandacaru	59.7 ± 14.9**	56.7 ± 14.1
Bebedouro	52.1 ± 13.7	56.2 ± 14.3

* Based on 260 data points (weekly evaporation for 1968, 1971, 1976, 1978 & 1982), the same data are plotted in Fig. 4 & 5.

** Mean ± standard deviation.

At both these locations the Agro-meteorological observatories are situated at the center of

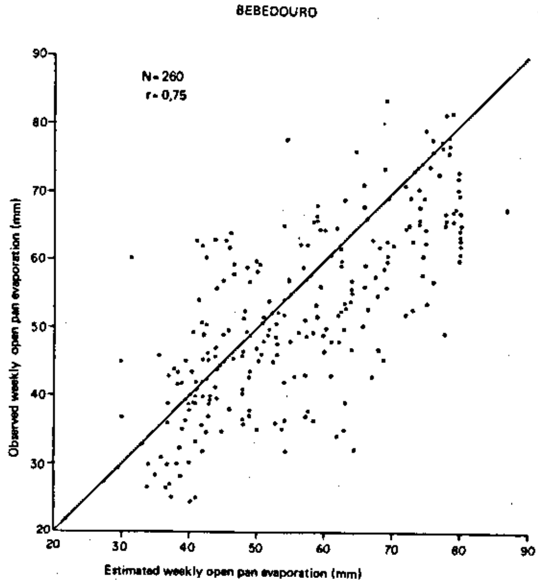


FIG. 4. Comparison of observed and estimated (using equation 13) pan evaporation data for Bebedouro using 260 data points (weekly data of 1968, 1971, 1976, 1978 of 1982).

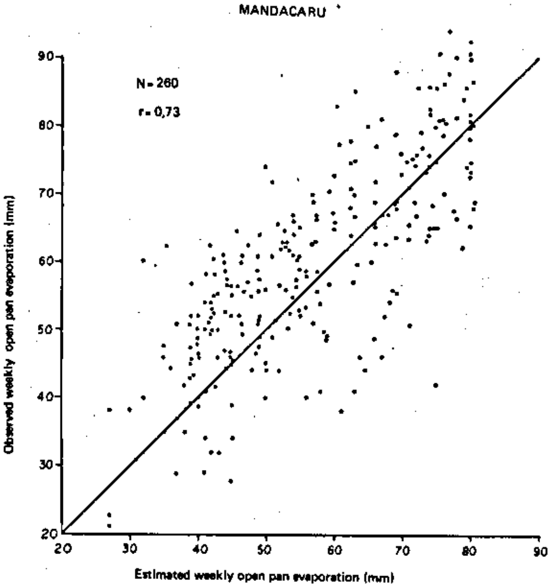


FIG. 5. Comparison of observed and estimated (using equation 13) pan evaporation data for Mandacaru using 260 data points (weekly data of 1968, 1971, 1976, 1978 of 1982).

the agricultural research Center, surrounded by irrigated projects. The intensity, closeness to irrigated area and water-body is more for Bebedouro compared to Mandacaru. In addition, Mandacaru area presents a dry area on one side. Because of this situation it appears that the dry advection at Mandacaru and wet advection at Bebedouro modified the general atmospheric evaporativity. It is not the aim of the authors to attribute all these deviations to the advection, but the presented model also has some deficiencies, like:

i) with overcast sky without rain can reduce evaporation, and

ii) evaporation can be high even with a rain, as this may occur instantaneously and sky will be cleared immediately in tropical dry climates.

However, these do not present the regular phenomena. Therefore, the regular variations observed in the estimated deviations at these two locations separated by about 1° lat. can be reasonably attributed to the localized effects - which are negligible under real farmers condition -, rather than to general atmospheric conditions. One can achieve better predictive equations for individual locations using more information. However, in the present situation the data is limited and the method should work for entire northeast Brazil.

It was also tried to compare with the long-term averages the values which generally are being used by many scientists in the past in the agroclimatological studies. Table 11 presents the correlation between observed and estimated open pan evaporation and with average for 20 years based on 14 values (for weeks 1, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48 and 52). For almost all the five years the correlation coefficients are superior with the presented method (Type 1 - Table 11) compared to use of averages for all years (Type 4 - Table 11).

TABLE 11. Correlation coefficients between observed and estimated values of pan evaporation during five years for Bebedouro.

Years Type*	Correlation coefficient**				
	1968	1971	1976	1978	1982
1	0.93	0.82	0.68	0.91	0.88
2	0.87	0.76	0.10	0.88	0.78
3	0.77	0.74	-0.01	0.81	0.79
4	0.85	0.70	0.04	0.82	0.82

* 1 - Correlation between observed and estimated using Eq. 13 open pan evaporation;

2 - Correlation between observed and estimated average open pan evaporation using Eq. 6 corrected by Reddy (1979b) method for each year;

3 - Correlation between observed and estimated average open pan evaporation using Eq. 6;

4 - Correlation between observed and average of 20 years open pan evaporation;

** - Correlation coefficients based on 14 values (weeks 1, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 48 and 52).

Table 11 also presents the correlation coefficients between observed and estimates of weekly evaporation from average monthly values by extrapolation (Type 3 - Table 11); and observed and estimates of weekly evaporation from average monthly values by extrapolation multiplied by a factor (Type 2 - Table 11) that relates to precipitation (Reddy 1979b) as:

$$PE_n = PE'_n \; (1 \pm 0.06 \left[Z_n\right]^{1/3}) \qquad ..(15)$$

$$\text{Where } Z_n = C' (\Delta R_n + \frac{1}{3} \Delta R_{n-1}) \qquad ..(16)$$

C' = 1 for weekly rainfall data; 7 for daily rainfall data

PE_n = Estimated potential evapotranspiration on n^th week, mm/week

PE'_n = Normal weekly pan evaporation on n^th week, mm/week

ΔR_n = $R_n - R'_n$

R_n = Weekly rainfall in year y on n^th week, mm/week

R'_n = Normal weekly rainfall on n^th week, mm/week.

+ 0.06 ir Z_n is negative or - 0.06 if Z_n is positive an $\left[Z_n\right]$ is the absolut value of Z_n.

In all these cases the method presented in this approach seems to be superior to other methods and next in order comes the method of Reddy (1979b).

Therefore, if the interest is to calculate monthly average potential evapotranspiration or pan evaporation then Eq. 6 and if the interest is to calculate weekly PE or E of individual years Eq. 13 can be used.

CONCLUSIONS

In the past, majority of the researchers used the average weekly potential evapotranspiration (extrapolated from montly averages). Even thoug the yearly variation in the case of potential evapotranspiration or pan evaporation are not as high as precipitation; they are still relatively large (as high as 40% or more). Therefore, it was felt necessary to identify or develop a suitable method for the estimation of weekly potential evapotranspiration. However, the basic problem in these studies is the availability of the input data (meteorological data), even though the literature is replete with methods for the estimation of potential evapotranspiration or pan evaporation. The basic meteorological data are available only for a few locations and for a few recent years. When compared to other precipitation networks we invariably find more parameters present in the agroclimatic studies.

In this study, therefore, an attempt was made to derive a simple regression model that basically utilizes precipitation. After trying several forms, the two most important parameters that related to potential evapotranspiration were latitude and precipitation. Generally, the R^2 is substantially high during the six-month period when the sun is in the northern hemisphere. The basic data used in this regression study were that of Hargreaves potential evapotranspiration estimates for 31 locations well distributed over Brazil. These values were corrected using a correction factor developed based on comparison with open pan evaporation data. The monthly regression coefficients were linearly interpolated for weekly interval and tested for their applicability to weekly data of individual years at Bebedouro and Mandacaru. The estimates appear to be good with high correlation; also these correlations are superior to the correlations obtained with three other procedures that are in use in the agroclimatic studies.

There can be some draw backs with any regression approach using few environmental factors or for the matter of fact any other sophisticated method that don't use all the physical processes involved in the process of evaporation. Few such draw-backs with the present approach are: i) overcast sky without rain can reduce evaporation; ii) even on a rainy day, evaporation may be high, as rain may occur instantaneously and sky will be cleared immediately in tropical dry climates. However, these are not regular phenomena.

ACKNOWLEDGEMENTS

The authors are thankful to Mr. José Clétis Bezerra for the cartographic assistance; Mrs. Elaria da Glória da Silva Elpidio, for the assistance on the computer and Mrs. Márica Cordeiro Ferreira for typing the manuscript.

REFERENCES

BAVEL, C.H.M. van. Combination (Penman Type) methods. In: CONFERENCE ON EVAPOTRANSPIRATION AND ITS ROLE IN WATER RESOURCES MANAGEMENT, Chicago, 1966. Proceedings ... St. Joseph, Michigan, Amer. Soc. Agric. Eng., s.d. p.48.

BRASIL. SUDENE. Dados evaporimétricos. s.l., 1973. v.1.

BRUTSAERT, W. Evaluation of some pratical methods of estimating evapotranspiration in arid climates at low latitudes. Water Resour Res., 1:187-91, 1965.

CAMPBELL, R.B. & PHENE, C.J. Estimating potential evapotranspiration from screened pan evaporation. Agric. Meteorol., 16:343-52, 1976.

FRERE, M. A method for the practical application of the Penman formula for the estimation of potential evapotranspiration and evaporation from a free water surface. Roma, FAO, 1978. (FAO, Agp. Ecol; 1).

GRINDLEY, J. Estimation and mapping of evaporation. In: SYMPOSIUM ON WORLD WATER BALANCE, 1, Proceedings . . . Paris, 1970 (AIHS, IASH - UNESCO. Publication, 92).

GLOVER, J. & MCCULLOCH, J.S.G.I. The empirical relation between solar radiation and house of sunshine. Quart. J. Ray. method. Soc., 8A:172-95, 1958.

HARGREAVES, G.H. Precipitation dependability and potentials for agricultural production in Northeast Brazil. Logan, Utah. EMBRAPA/Utah State Univ. 1974.

HARGREAVES, G.H. World water for agriculture (precipitation probabilities, climate and moisture adequacy). Logan, Utah. Utah State Univ., Logan, Utah. 1977.

MCCAUGHEY, J.H. A test of the Penman combination model for potential evapotranspiration. (Publ. Climatology, 1), Hamilton, Ontario, McMaster Univ., 1968.

MONTEITH, J.L. Evaporation and environment. Symp. Soc. Expl. Biol., 19:205-34, 1965.

MONTEITH, J.L. Principles of environmental physics. London, Arnold, 1973. p.241.

PAPADAKIS, J. Evaporation and potential evapotranspiration measuring and calculating them. Buenos Aires, Argentina, s.ed., 1977.

PENMAN, H.L. Evaporation: an introductory survey. Neth. J. Agric. Sci., 4:9-29, 1956.

PENMAN, H.L. Natural evaporation from open water, bare soil and grass. Proc. Roy. Met. Soc., London, 193:120-46, 1948.

PENMAN, H.L. Weather, plant and soil factors in hidrology. Weather, 16:207-19, 1961.

PENMAN, H.L. & SCHOFIELD, R.K. Some physical aspects of assimilation and transpiration. Symp. Soc. Exp. Biol., 5:115-29, 1951.

PRUITT, W.O. Empirical method of estimating evapotranspiration using primarily evaporation pans. Conference on evapotranspiration and its role in water resources management. Chicago, Illinois, 1966. Proceedings . . . St. Joseph, Michigan, s.d. p.57-61.

REDDY, S.J. User's manual for water balance models. ICRISAT Patancheru, India, ICRISAT, 1979a. p.28.

REDDY, S.J. A review - measurements and estimates of evaporation and evapotranspiration. Patancheru, India, ICRISAT, 1979b.

REDDY, S.J. & RAO, K.R. An empirical method for the estimation of evaporation from the free surface of water. Indian J. Meteorol. Geophys., 24:137-52, 1973.

REDDY, S.J. & REDDY, R.S. A new method of estimation of water balance. INTERNATIONAL TROPICAL METEOROL. MEETING, Nairobi, Kenya, Amer. Met. Soc., 1973. p.277-80.

REDDY, S.J. & VIRMANI, S.M. Potential evapotranspiration estimates in the semiarid West African region. Patancheru, India, ICRISAT, 1980. (ICRISAT Departmental Progress Rept. Agrocl., 3).

SILVA, W.J. da; SEDIYAMA, G.C. & BERNARDO, D.T.C.C. Estimativa da evaporação potencial em condições de campo, usando tanque "Classe A" modificado. In: CONGRESSO BRASILEIRO DE AGROMETEOROLOGIA, 2, Pelotas, 1981. Anais . . . Pelotas, Sociedade Brasileira de Agrometeorologia, 1981. p.119-21.

STANHILL, G.A. A comparison of methods of calculating potential evapotranspiration from climatic data. Israel J. Agric. Res., 11:159-71, 1961.

STANHILL, G.A. The control of field irrigation practices from measurements of evaporation. Israel J. Agric. Res., 112:51-62, 1962.

STEPHENS, J.C. & STEWART, E.H. A comparison of procedures for computing evaporation and evapotranspiration. s.l. Inter. Assoc. Scientific hidrology, 1963. p.123-33. (IASH. Publ., 62).

THOM, A.S. & OLIVER, H.R. On Penman's equation for estimating regional evaporation. Q.J.R. Meteorol. Soc., 103:345-7, 1977.

THOM, A.S.; STEWART, E.T.; OLIVER, H.R. & GASH, J.H.C. Comparison of aerodynamic and energy budgest estimates of fluxes ofer a pine forest. Q. J.R. Meteorol. Soc., 101:93-106, 1975.

VIEIRO, de A.P.; MÁRIO, A.V.S. & OSÓRIO, G.A.V. Zoneamento do potencial de energia solar do nordestes. Campina Grande, UFPB, 1981. 51p.