EVALUATION, ANALYSIS AND MODIFICATION OF THE BLANEY-MORIN - NIGERIA (BMN) EVAPOTRANSPIRATION MODEL

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ABSTRACT

The analytical approach of the Blaney-Morin-Nigeria (BMN) evapotranspiration model was applied to data sets obtained from seventeen locations in Nigeria and the values of the constants m and H in the BMN model, Equation 1 were not as consistently comparable as expected. Thereupon, the Standard Difference (SDF) method was applied to each of the seventeen locations (designated as model ETPP4), to each of the five regions formed by pooling data from meteorologically similar locations (ETPP3) and to the pooled data from all locations (ETPP1). The values of m and H thus obtained were consistently comparable and within the range considered acceptable for the country. While the models predict potential evapotranspiration (PET) more accurately than the Penman equation under the Nigerian conditions, their performances are similar to that of the BMN model. However, ETPP4 and ETPP3, produce better prediction in their corresponding locations and regions while ETPPI predicts PET slightly better than the 3MN model at those locations where the BMN model was not originally evaluated. Consequently, the SDF method is recommended as a procedural modification of the development of the BMN model and the most general form of the models, ETPPI (m = .29, H = 508) is recommended as a refinement of the BMN model.

INTRODUCTION

The Blaney-Morin-Nigeria (BMN) evapotranspiration model (Equation 1) was developed for application in Nigeria [2]. However, meteorological data used in developing the BMN model were obtained only from Samaru-Zaria. Meteorological data obtained from locations representative of all the climatic regions of the country should have been used. Duru,[2] determined the constants m and H of the BMN model (after rearranging Equation 1 into Equation 2) using the Muskingum approach to the analytical method of streamflow routing. When the relationship is not linear, an alternative approach must be adopted [3]. Duru's [1] Blaney- Morin-Nigeria (BMN) model (Equ. 1 or Equ.2) involves an exponentially based variable, R. The use of the Muskingum approach to the analytical which is exactly what Duru [1] did, appears inappropriate

$$PET = P\frac{(0.45t+8)(H-R^m)}{100} \quad \text{........ (1)}$$

$$H = \frac{100PET + p(0.45t+8)R^m}{p(0.45t+8)} \quad \text{............(2)}$$

where PET is the potential evapotranspiration (mm/day)
p = is the ratio of maximum sunshine hours for the period of interest to the annual maximum.
t = is temperature, ^{O}C
R = is relative humidity, %
H and m are empirical constants which were evaluated as 520 and 1.31 respectively.

The BMN model developed by Duru involves a ratio of maximum sunshine hours for the period of interest to the annual maximum (P). This parameter was however, replaced by a radiation ratio, r_f when the model was evaluated. Although this ratio (r_f) appropriately modifies the PET predictions during the harmattan months while it is virtually the same during the rest of the year [2], there is the need to apply it (r_f.) in the development of the model in order to incorporate its effect during the harmattan months in the final form of the model. The model developed and evaluated by Duru, [1] should have been of the form:

$PET = r_f\,(0.45t + 8)(H - R^m)/100$ .... (3)

where all the terms have already been defined. Duru [2] has indicated that all his analysis including calculating over 12120 data points, plotting 101 data sets each comprising 120 data points and determining the pattern of scatter of each plot were manually carried out. There is ample opportunity for error(s) in this approach.

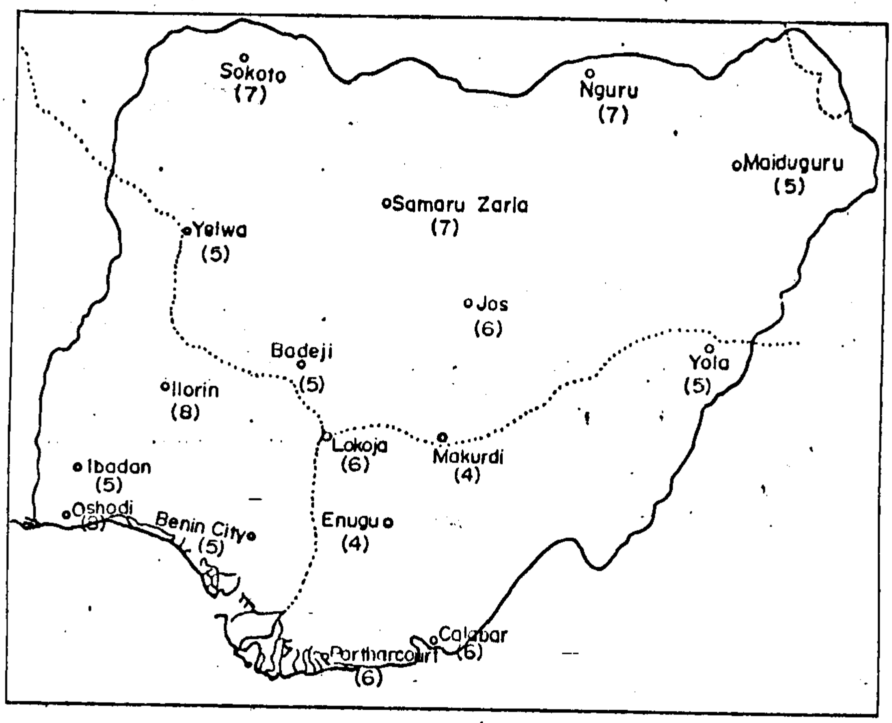
Based on the foregoing, the objectives of this study include:

(i) Critical evaluation and analysis of the BMN model.

(ii) Modification of the model, if necessary, to make it more applicable to all climatic regions of Nigeria.

MATERIALS AND METHODS

Meteorological data obtained from seventeen locations throughout the country (Fig. 1) and used in the study included temperature, relative humidity, open-water evaporation measured with Class-A pan (E-class A) and appropriate values of the radiation ratio, r_f. In addition, wind speed, sunshine and vapour pressure parameters required for evaluating the Penman [4] equation were also obtained. Observed potential evapotranspiration (ETPO) was defined as 0.7 E-class A.



(Number in brackets indicate number of years of data)

Fig. 1: Map of Nigeria showing sources of Meteorological data.

The BMN model (Equ. 3) was used to predict PET at each of the seventeen locations. Thereafter, the constants m and H (Equ. 2) were determined using the interactive method adopted by Duru [1] for each of the seventeen location as well as for the pooled data from all the locations. Each data set was divided into two parts; one part was used for determining the constants m and H while the other part was used for evaluating the model. The above determinations for the various locations as well as for the five regions established by pooling data from meteorologically similar locations were repeated using the Standard Difference (SDF) method.

The basic principle of the SDF method is that of an interactive least squares method of m and H to minimize the standard difference between the predicted and observed potential evapotranspiration values. In this method, a given value of m was adopted and values of H varied between two limits and for each, PET and SDF values were obtained using Equations 3 and 4.

$$SDF = \sum_{I}^{N}[(PET_i - ETPO_i)/N]^{1/2} \quad \text{…………… (4a)}$$

for N > 100

$$SDF = \sum_{I}^{N}[(PET_i - ETPO_i)^2/(N-1)]^{1/2} \quad \text{……. (4b)}$$

for N < 100

where N is the number of data points and PET and ETPO (predicted and observed potential evapotranspiration respectively) are in mm/day.

The H value at which the smallest value of SDF was obtained was adopted as the appropriate H- value corresponding to the given m-value. The m value was then varied and the process repeated. The limits of m were 1.0 and 2.0 and varied at 0.01 increments after Duru [1] while H was limited to arange of 300 and 1500, based on results of preliminary tests using data from a few locations, and varied at increments of 1.0. Hence there were a total of 101 accepted values of m and H sets and 10 1 computed smallest SDF values. The m and H set which produced the smallest SDF was adopted as the m and H values determined for the given model.

The performances of the various models (ETP 1 - pooled data, ETPP3 - regional data, ETPP4 - individual location data), the BMN model (ETPP2), and the Penman equation (ETPEN), in predicting PET were evaluated statistically and graphically as well as by comparing the predicted raw values.

RESULTS

Table 1 gives the values of m and H determined using Duru's [1] methodology. The values of m and H determined for the locations and for the pooled data are not as consistently comparable to those for Samaru - Zaria as would be expected since the BMN model was developed, for application in Nigeria, using data obtained only from Samaru - Zaria. Table 2 shows that the BMN model generally predicted PET better than other models with the m and H values determined using Durus methodology. This suggests that the values m = 1.31 and H = 520 may be within the consistent *range* of these constants that should be obtained at the various locations and for the entire country. The values of m and H determined using the SDF method are also shown in Table 1 while Figs. 2 - 5 present graphically the general trend of the performances of the various models in predicting PET in this case. Table 1 presents the correlation coefficients between the observed and predicted PET, while Table 4 gives the corresponding standard differences (SDF).

Table 1: Values of m and H determined using Dur's (1984) Method and the SDF Method

Location	Duru's method		SDF Method	
	m	H	m	H
Port Harcourt	1.72	2471	1.20	419
Lokoja	1.71	1741	1.52	997
Calabar	1.67	1491	1.36	605
Oshodi	1.44	752	1.23	414
Benin City	1.56	958	1.17	342
Enugu	1.73	3758	1.31	519
Ibadan	1.53	907	1.26	451
Makurdi	1.60	1844	1.37	614
Ilorin	1.52	605	1.37	617
Badegi	1.51	533	1.13	343
Jos	1.19	825	1.21	450
Yola	1.51	841	1.19	478
Yela	1.38	1128	1.29	546
Samaru-Zaria	1.34	852	1.19	411
Maiduguri	1.45	927	1.07	391
Nguru	1.89	3529	1.30	519
Sokoto	-	-	1.36	644
Sokoto/Nguru Region	-	-	1.27	519
Sarnaru/Y ola/Yelwa/ Jos Region	-	-	1.25	492
Badegi/Ilorin/Makurdi Region	-	-	1.29	494
Ibadan/Enugu/Benin City Region	-	-	1.31	511
Port Harcourt/Oshodi/Calabar	-	-	1.28	486
Entire Country (Pooled data)	1.43	689	1.29	508

Table 2: Observed and Predicted PET by the BMN model and Alternative models with m and H determined using Duru's (1984) method for selected locations.

Location	Year/Month	Observed PET mm/day	BMN Model	Model for the location	Model for entire country (pooled data)
Sarnaru-	6.3	6.37	10.7	8.4	
Zaria	Feb	5.6	6.63	11.3	8.7
	March	7.0	8.40	14.2	11.1
	June	5.2	3.81	8.6	3.4
	July	4.2	3.39	8.2	2.5
	Oct	3.4	3.68	8.3	3.3
	Nov	3.7	5.15	9.3	6.4
	Dec	3.8	5.70	9.8	7.4
Ibadan	1 969/Jan	2.6	3.29	1.4	2.6
	Feb	3.2	3.62	2.2	3.1
	March	3.8	3.75	1.4	2.8
	June	2.6	2.95	-0.1	1.7
	July	1.9	2.69	-0.9	1.3
	Oct	3.0	3.04	0.2	1.9
	Nov	3.0	3.0	0.7	2.1
	Dee	2.5	3.36	-1.7	2.7
Bcnin City	1972/Jan	1.9	3.16	-0.5	2.2
	Feb	2.1	2.73	-1.6	1.5
	March	2.4	3.49	-0.5	2.4
	June	1.8	2.84	-1.3	1.7
	July	1.8	2.52	-3.0	0.9
	Oct	1.8	2.94	-1.8	1.6
	Nov	1.9	3.12	-0.4	2.2
	Dec	1.9	3.07	-0.4	2.1

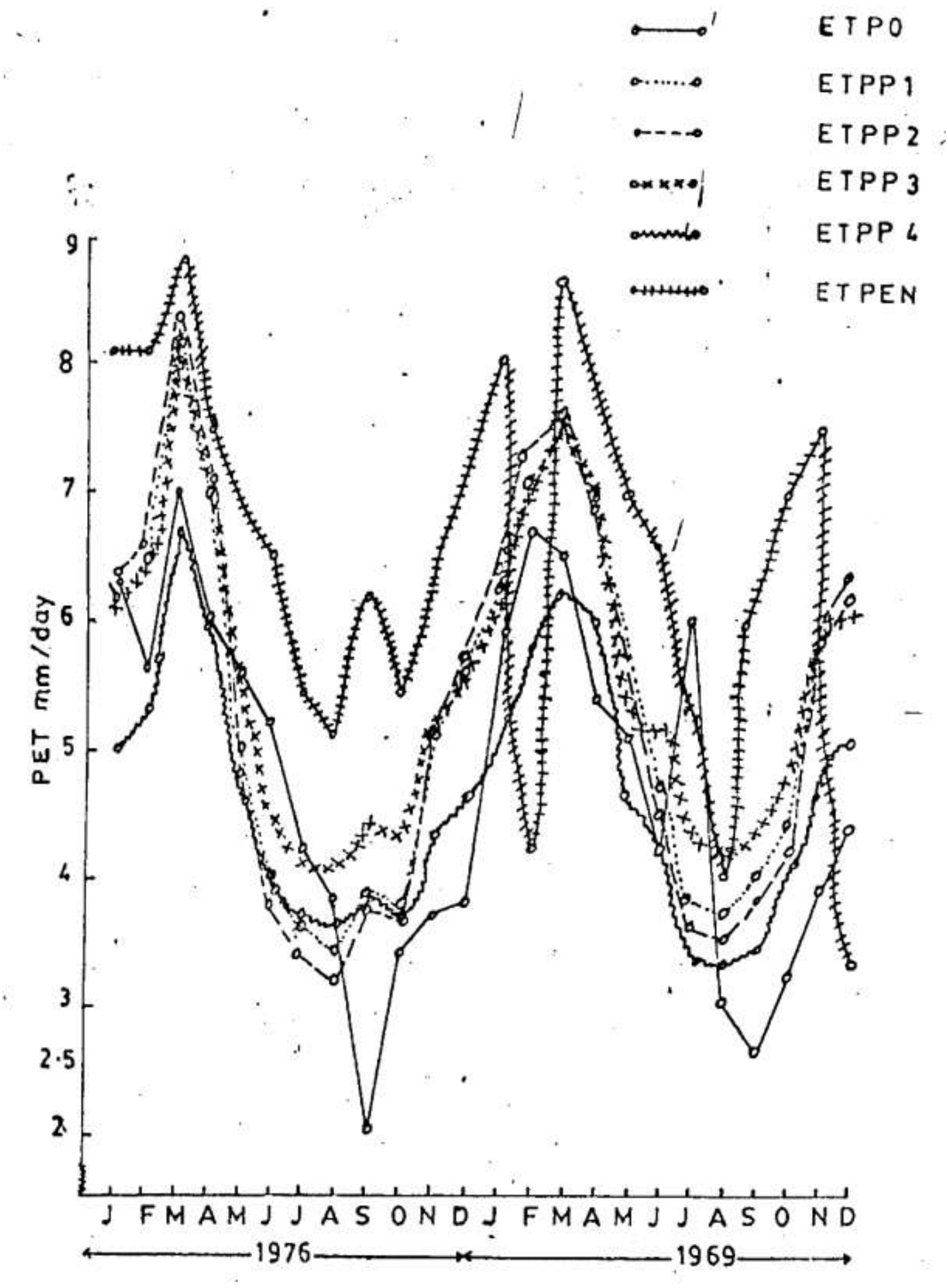
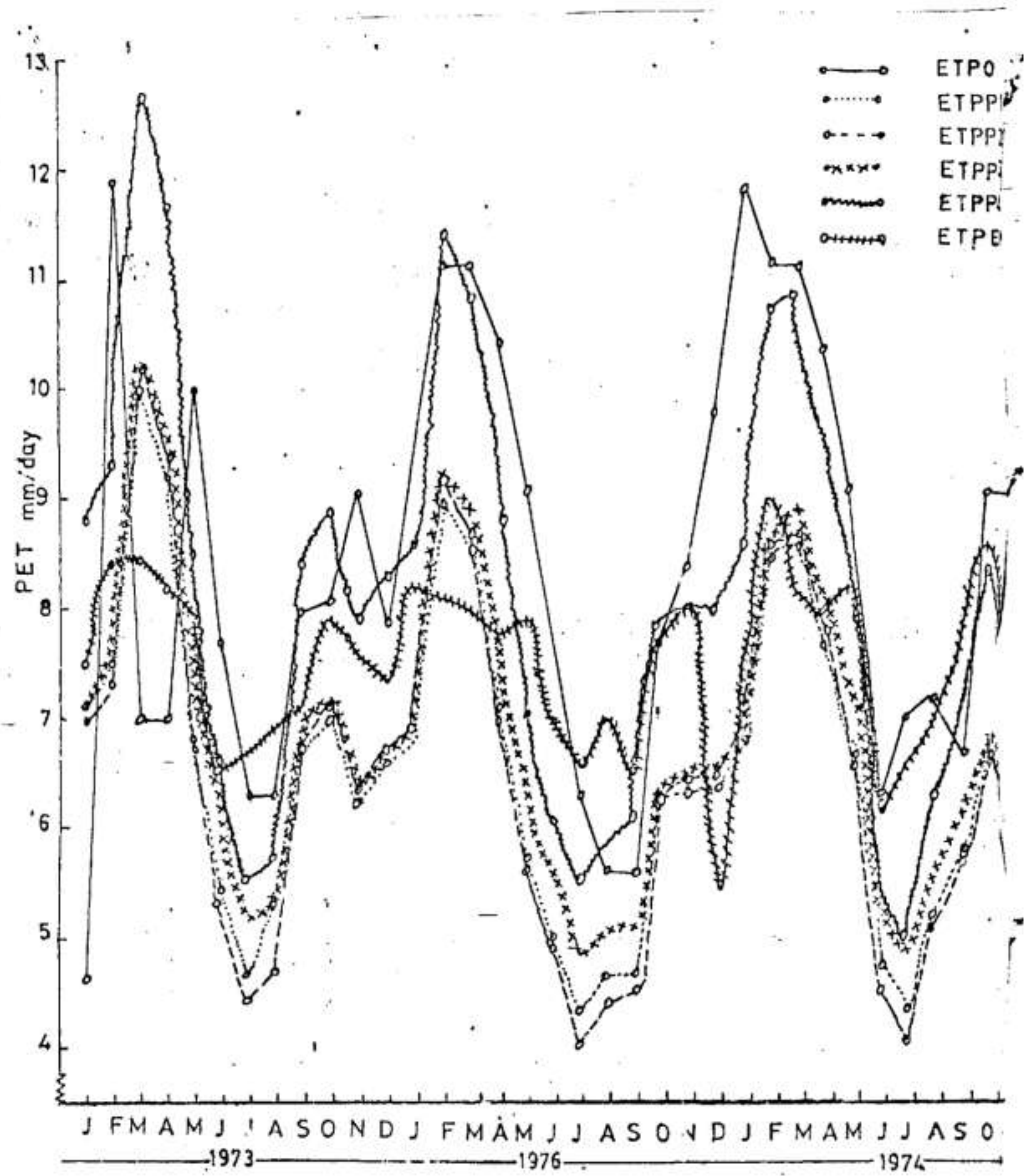


Fig. 2: Observed and Predicted PET for Samaru Location.



;Fig. 4: Observed and Predicted PET for Calabar Location

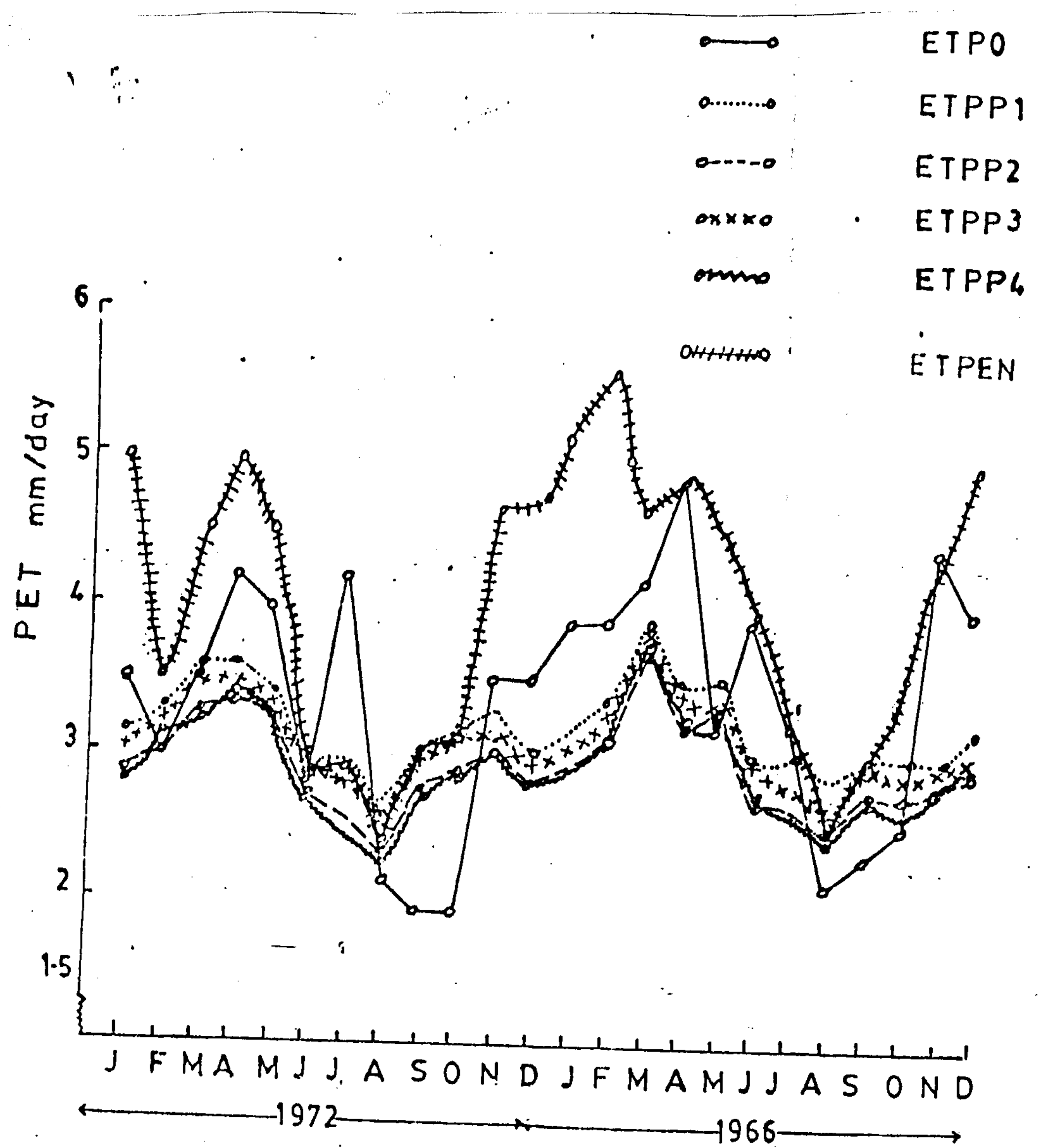


Fig. 4: Observed and Predicted PET for Calabar Location.

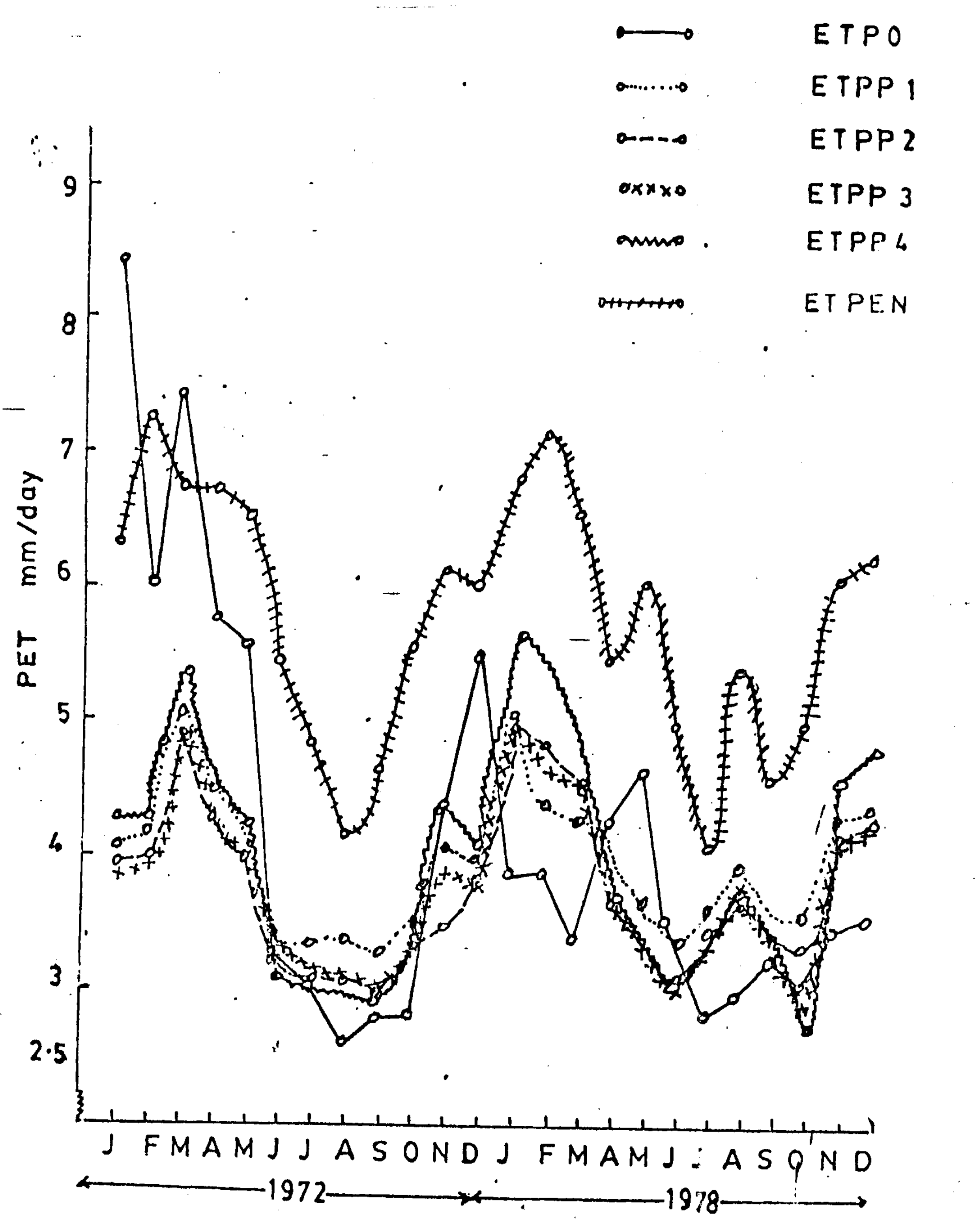


Fig. 5: Observed and Predicted PET for Ilorin Location.

Table 3: Correlation Coefficients between observed and Predicted for the various model equation forms developed using the SDF

Location	ETPP1	ETPP2	ETPP3	ETPP4	ETPEN
Sokoto	0.55	0.56	0.54	0.56	0.53
Sarnaru-Zaria	0.71	0.71	0.73	0.74	0.38
Jos	0.75	0.75	0.74	0.73	0.63
Vola	0.76	0.76	0.80	0.82	0.49
lIorin	0.46	0.46	0.45	0.46	0.61
Enugu	0.36	0.35	0.35	0.35	0.45
Benin City	0.80	0.78	0.78	0.80	-
Calabar	0.50	0.51	0.50	0.53	0.73
lbadan	0.67	0.66	0.65	0.67	0.61
Oshodi	0.15	0.15	0.15	0.15	0.13
Port Harcourt	0.09	0.10	0.09	0.06	0.25
Nguru	0.47	0.46	0.35	0.43	0.17

Table 4: Standard differences between observed and predicted PET using the various model equation forms

Location	ETPP1	ETPP2	ETPP3	ETPP4	ETPEN
Sokoto	2.6323	2.6328	2.3638	1.9155	1.9354
Nguru	1.4472	1.4282	1.3658	1.4654	1.3068
Sarnaru-Zaria	1.2491	1.2988	1.2662	0.9358	2.4926
Jos	1.2142	1.2206	1.2850	1.2127	1.9422
Yola	1.4287	1.5271	1.2337	1.0642	1.0883
Ilorin	1.4383	1.4 748	1.4901	1.4401	2.0883
Enugu	1.8629	1.9540	2.0315	1.9622	1.7725
Benin City	1.2000	0.9681	0.8508	0.7265	-
Calabar	0.7739	0.8718	0.8552	0.8653	0.9618
lbadan	0.7817	0.5749	0.4827	0.5278	2.1860
Oshodi	1.0590	1.0525	1.0387	1.0359	2.0282
Port Harcourt	1.0632	1.0864	1.0646	1.0745	1.170

Table 5: Unrealistic observed PET values (ETPO) for selected Locations based on raw values of ETPO

Location	Year	Unrealiable ETPO Values (mm/day)		Trend of PET at relevant period of the year (mm/day)	
Sokoto	1973	11.9	(Feb)	4.6	(Jan), 7.0(march),
		10.5	(May)	7.0	(April), 7.7 (June)
Enugu	1972	2.5	(Feb)	8.4	(Jan), 8.8(march),
				3.5	(April), 4.5 (May)
Calabar	1972	2.8	(June)	4.2	(April), 4.4 (May)
				4.2	(July).
Port Harcourt	1978	6.4	(June)	3.9	(May), 4.2 (July)
				2.6	(August).
	1977	1.4	(Jan)	4.2	(Feb), 4.2 (March).
Nguru	1972	5.4	(June)	8.9	(April), 8.6 (May)
				6.1	(July), 7.2 (August).
Benin City	1977	1.8	(June)	3.9	(May), 2.8 (Sept.)
Oshodi	1973	1.1	(April)	4.2	(May), 4.2 (July),
				4.2	(May)

DISCUSSION

The fact that the application of Duru's [1] methodology to the various locations and the pooled data did not produce consistently comparable values of m and H is indicative of the limitations of Durus methodology. The SDP method, however, produced consistently comparable values of m and H for the various locations, regions and the pooled data for the entire country (Table 1). These values of m and H are therefore considered to be within the ranges acceptable for the country. Consequently, although the Muskingum approach to analytical method of streamflow routing, adopted by Duru [1] in developing the BMN model, produced m and H values acceptable at the Samaru -Zaria location, the theoretical basis of the method is not applicable generally for evapotranspiration process either at individual locations across the country or for the entire country on a regional basis.

The apparent unsound theoretical basis of Duru' s methodology is also reflected in the negative values of predicted PET obtained when the methodology was applied in determining m and H at individual locations across the country (Tabl 2).

With the m and H values obtained using the SDF method, the predictions of the model for the individual locations (ETPP4) were consistently closest to the observed PET values throughout the year while those for the regional model (ETPP3), the BMN model (ETPP2) and the model for the pooled data (ETPPl) were basically the same, with ETPP3 showing a slight overall edge over the other two when raw figures are considered. In general one of the three models (ETPP3, ETPP2 and ETPP 1) alternatively predicted PET better than the other two during different months of the year with the prediction of ETPP2 and ETPP 1 being more consistently close. Specifically, ETPPI predicted PET slightly better than ETPP2 at those locations where the original BMN model was not evaluated. These results confirm that the performance of the various models improved as the geographical area covered by the model became more restricted.

The Penman [4] equation (ETPEN) generally over- predicted PET most of the year confirming the unsatisfactory performance of the equation in Nigeria as has been observed by Duru [1]. However, it must be appreciated that the Penman equations has been acclaimed as one of the best PET prediction equations world-wide. Its poor performance in Nigeria may well be attributed to poor quality and sometimes non-availability of the extensive meteorological data required by the equation. Significant departures, for portions of the year, of the observed potential evapotranspiration (ETPO) from the general and expected trend during such periods (Table 5), reveal the unreliability of part of such data used in this study.

Statistical evaluation of the performance of the models confirm the trend already presented. The magnitude of the correlation coefficients between the observed and predicted PET for the various models are virtually the same for a given location but vary between locations (Table 3).

CONCLUSION

The evaluation and analysis made in this study show that, although the Muskingum approach to analytical method of streamflow routing adopted for the development of the Blaney-Morin-Nigeria (BMN) model produced acceptable m and H values at the Samaru-Zaria location, the method is not applicable generally in other climatic zones in the country or for the entire country on a regional basis. The standard difference (SDF) method for determining the constants m and H is therefore recommended as a procedural modification of the BMN model.

The BMN model and the various models developed using the SDF method predict potential evapotranspiration (PET) satisfactorily in the country. However, ETPP4 and ETPP3 produce better predictions in their corresponding locations and regions. Consequently the most general form of the models, ETPPI (m = 1.29, H = 508) which predicts PET slightly better than the BMN model at those locations where the original BMN model was not evaluated is recommended as a refinement of the BMN model.

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