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# Evaluation of Four $ET_o$ Models for IITA Stations in Ibadan, Onne and Kano, Nigeria.

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**Abstract**

Records of climatic variables (Solar radiation, Maximum and Minimum Temperature, Maximum and Minimum Relative Humidity and Wind speed) were collected from three International Institute of Tropical Agriculture (IITA) Stations namely Ibadan, Kano and Onne in Nigeria. For Ibadan, a 36-year (1973 – 2008) record was obtained, for Kano, a 29-year (1980 - 2008) record was obtained and for Onne, a 31-year (1977 - 2006) record was obtained. Evapotranspiration rates for each of the stations were estimated using the FAO-56 approach. The performance of four ET models (Blaney-Morin-Nigeria (BMN), Hargreaves-Samani, Priestly-Taylor and Jensen-Haise models) were evaluated with reference to FAO 56 Model making use of ET estimated from these models. The BMN model was found out to be the best model that can be applied to estimate ET in each of these stations because it has a high correlation value with the values obtained from FAO56-PM model along with favourable statistic values and it requires a considerably less number of variables for its estimation with correlation (r) values of 0.7, 0.77 and 0.75 respectively for Ibadan, Onne and Kano.

**Key words:** Evapotranspiration, FAO-56 Penman-Monteith, Blaney-Morin Nigeria

## 1. Introduction

Water being a major ingredient of life is becoming scarce in many parts of the world and also in Nigeria. Over the years, it is widely believed that any change in climate will have a significant impact on the availability of water. A lot of water is needed for agricultural practices and also for domestic purposes. In view of this it is imperative to have the knowledge of the rate at which water is being returned to the atmosphere either form water bodies, reservoirs, land surfaces and from plant bodies.

The rate at which water returns from the earth (also from vegetations) back to the atmosphere in the form of vapour is referred to as 'evapotranspiration'. Its knowledge helps in estimating irrigation requirements and carrying out its scheduling, estimate moisture loss from reservoirs and river basins.

Dependency on rainfall for future crop production has become a major constraint for sustainable food production in the developing counties (Adebayo *et al*. 2009). Rainfall pattern in recent times has been irregular and this makes it imperative to practice irrigation during crop production. Irrigated agriculture accounts for about 70% of the available fresh water globally (Fischer *et al.* 2006).

Many approaches have been developed and adapted for various applications based on available input data for the estimation of reference evapotranspiration; there is still a remarkable range of uncertainty related to which method is to be adopted specifically in the calculation of reference evapotranspiration for short grass at a given area. Thus, for the purposes of establishing a common method which can provide a more accurate $ET_o$ estimation, these estimation methods were researched on the basis of their variability in input variables (Alkaheed *et al*. 2006).

Since the accuracy of estimated values of $ET_o$ is important for water resources planning and management, irrigation scheduling, control and agricultural productivity; it has given rise to numerous researches that were carried out in different parts of the world to ascertain the best model which is suitable for application in such parts. Similar researches have been carried out in Japan (Alexandris *et al.* 2008), Bulgaria (Popova *et al.* 2006), Central Serbia (Alkaheed *et al*. 2006), a region of Florida in the United States of America (Hargreaves and Samani, 1982) and a region in south western Nigeria (Adebayo *et al*. 2009).

Among the methods used in estimating reference evapotranspiration is the method universally acceptable model, the FAO – 56 Penman – Monteith method due to its better performance in many regions of the world when compared with other models (Allen *et al*. 1996). This model has been standardized and adopted for use by the Food and Agriculture organization. In Nigeria, a model was developed by Duru (1984) called the Blaney-Morin-Nigeria model to estimate reference evapotranspiration and was widely judged to be most suitable to Nigeria's condition by the Nigerian Institute of Agricultural Engineers (NIAE) (Duru, 1984). Other models for estimating $ET_o$ include the Jensen Haise approach, Hargreaves-Samani Approach (Hargreaves and Samani, 1982; 1984) and the Priestly-Taylor model (Priestley and Taylor, 1972).

In this research work, the selection of models used was based on the three general approaches to estimating reference evapotranspiration; temperature methods, radiation methods and combination methods. The purpose of this evaluation is to ascertain which method apart from the FAO56-PM that can be best applied in Nigeria for the estimation of $ET_o$, that is easiest to use in terms of parameters required and that can accurately and consistently capture evapotranspiration losses in the country.

## 2. MATERIALS AND METHODS

*2.1 Study Area*

The area considered under this study covers the whole of Nigeria with specific emphasis on three cities, Ibadan, Kano and Onne where IITA stations are located. It lies within latitudes $4^oN – 14^o$ N and Longitudes $2^oE – 15^o$ E. The country has an estimated population of 138,283,380 people (Source: Wikipedia) and a total land mass of 923,768km$^2$ (the 32$^{nd}$ largest country in the world) with about 1.4% of this land mass covered by water.

Special emphasis is placed on three location having distinct characteristics into which the climatic conditions of the country can be divided. They are:

i. Onne **(4°45′0″N, 7°00′0″E)**; near Port Harcourt having a humid climate characterized by swamps, heavy rainfall and mangrove forests. The region's soil is Thionic Fluvisol, having a mean annual rainfall of 2400mm, a unimodal rainfall pattern with annual maximum temperature ranging from 28-32$^o$C, annual minimum temperature ranging from 21-23$^o$C. It also has two distinct seasons; the lengthy and heavy rainy season and very short dry season. The rainy season spans February to November while the dry season occurs in the remaining months although precipitation of about 20mm do occur during this period.

ii. Ibadan **(7°23′47″N 3°55′0″E)**; is also one of the locations. It has a sub-humid climate which is characterized by rain forests and slightly heavy rainfall. Its rainfall pattern is Bimodal with mean annual rainfall of 1250mm. The region's soil in majorly Ferric Luvisols, its season are wet which from March through October and dry running through November to February having annual maximum temperature ranging between 27-34$^o$C and annual minimum temperature ranging between 20-23$^o$C.

   Both regions mentioned above are characterized with light wind speeds, (Oguntunde, 1998).

iii. The third location is Kano **(12°00′0″N 8°31′0″E)** which is situated in the northern region of the country. It has a semi-arid or savannah climate characterized with scattered trees and shrubs. The region has a high wind speed which carries large deposits of sand that are deposited in the area to replenish the soil removed by erosion. It has Ferric Latosol soils and the region has an annual mean rainfall of 748.1mm between 1988 and 2001. Its season can be divided into two, the wet/rainy season which occurs between May and September with temperature ranging between 24$^o$C-29$^o$C and the dry season between October and April with maximum temperature range between 28$^o$C-34$^o$C and minimum temperature range between 25$^o$C-27$^o$C.

*2.2 Models Used*

Four methods of computing evapotranspiration making use of empirical formulae were compared with the FAO 56 Penman-Monteith formulae to determine which can be best applied to Nigeria. The methods are the Blaney-Morin-Nigeria model, Hargreaves-Samani model, Priestley-Taylor formula and the Jensen Haise Model. The models were used to estimate $ET_o$ for the three study locations and are described below:

*(i)* ***FAO 56 Penman-Monteith approach:***

This method has been recommended as the sole method for the estimation of evapotranspiration certified by the FAO because it takes into consideration both physical and aerodynamic parameters. In calculating ET using this approach, the equation stated below was applied and the computation of all required data necessary for the calculation of ET was carried out using the laid out procedure given in Chapter 3 of the FAO paper 56 (Allen *et al*. 1998)

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

where

| | |
|---|---|
| $ET_o$ | reference evapotranspiration [mm $day^{-1}$], |
| $R_n$ | net radiation at the crop surface [MJ $m^{-2}$ $day^{-1}$], |
| G | soil heat flux density [MJ $m^{-2}$ $day^{-1}$], |
| T | mean daily air temperature at 2 m height [°C], |
| $u_2$ | wind speed at 2 m height [m $s^{-1}$], |
| $e_s$ | saturation vapour pressure [kPa], |
| $e_a$ | actual vapour pressure [kPa], |
| $e_s - e_a$ | saturation vapour pressure deficit [kPa], |
| Δ | slope vapour pressure curve [kPa °$C^{-1}$], |
| γ | psychrometric constant [kPa °$C^{-1}$]. |

*(ii)* ***Blaney-Morin-Nigeria Model (BMN):*** This method was applied following the steps laid down by Duru (1984) and it was easily carried out because of the few parameters needed to estimate ET using this model. The equation was given as;

$$ET = r_f\,(0.45T_a + 8)\,(520 - R^{1.31})/100 \quad (2)$$

where:
- $r_f$ = ratio of monthly radiation to annual radiation
- $T_a$ = mean monthly temperature in $^oC$
- R = mean monthly relative humidity

*(iii)* ***Priestly-Taylor Model:*** This model can be described by the following equation:

$$ET = \alpha\frac{\Delta}{\Delta + \gamma}(Rn - G)\frac{1}{\lambda} \quad (3)$$

where,
- α 1.26
- $\lambda$ the latent heat of vaporization [2.45MJ $kg^{-1}$ @ 20$^o$C]

Other parameters are as defined in equation 1 above.

*(iv)* ***Hargreaves-Samani Model:*** The equation that was applied while using this model to estimate reference evapotranspiration was given as;

$$ET = 0.0023(T_{max} - T_{min})^{0.5}\,(T_m + 17.8)R_a \quad (4)$$

where
- ET daily reference evaporation (mm$day^{-1}$),
- $T_{max}$ daily maximum air temperature ($^o$C)
- $T_{min}$ daily minimum air temperature ($^o$C)
- $T_m$ mean daily air temperature ($^o$C)
- $R_a$ extraterrestrial radiation (mm$day^{-1}$)

*(v)* ***Jensen-Haise Model***: Jensen-Haise model is used in computing reference evapotranspiration as reported by James, (1988) and is given as:

$$ET_r = C_T\,(T_{mean} - T_x)R_S \quad (5)$$

The data requirements for each of the five models applied is as shown in Table 1.

*2.3 Data Source:*

Records of climatic variables (Solar radiation, Maximum and Minimum Temperature, Maximum and Minimum Relative Humidity and Wind speed) were collected from three International Institute of Tropical Agriculture (IITA) Stations in Ibadan, Kano and Onne. For Ibadan, a 36-year (1973 – 2008) record was obtained, for Kano, a 29-year (1980 - 2008) record was obtained and for Onne, a 31-year (1977 - 2006) record was obtained. Data collections were done by IITA trained personnel and weather instruments installations conform to WMO standard. Agro-ecological characteristics of the sites and instrumentation, (Jagtap and Alabi, 1997).

*2.4 Data Analysis*

Five models were used to test the efficiency of the models used for estimating $ET_o$. They are;

i. The Mean Bias Error (MBE)

$$MBE = N^{-1}\sum_{i=1}^{N}(Pi - Oi) \quad (6)$$

ii. Measurement of the variability of the difference between the predicted and observed values;

$$S^2_d = (N - 1)^{-1}\sum_{i=1}^{N}(Pi - Oi - MBE)^2 \quad (7)$$

iii. The Mean Absolute Error (MAE); gives the mean difference between the observed and predicted values but more accurate for small or limited data.

$$MAE = N^{-1}\sum_{i=1}^{N}|Pi - Oi| \quad (8)$$

iv. The Root Mean Square Error (RMSE); similar in operation with the Mean Absolute Error (MAE) but preferred for use with large data.

$$RMSE = [N^{-1}\sum_{i=1}^{N}(Pi - Oi)^2]^{0.5} \quad (9)$$

v. The Coefficient of Correlation (*r*): Investigates the level of similarities between two sets of values.

$$r = \frac{\sum PO - \frac{\sum P \sum O}{N}}{\sqrt{(\sum P^2 - \frac{(\sum P)^2}{N})(\sum O^2 - \frac{(\sum O)^2}{N})}} \quad (10)$$

where O represents the observed $ET_o$ values (the FAO 56 model); P is the predicted values of $ET_o$ from the other models.

## 3. Results and Discussions

### *3.1 Statistical Analysis*

Data collected for the research were analyzed making use of the statistical tools mentioned in *section 2.4*. The Ms Excel software package was used for this. The results of the statistical analysis are shown in tables 2 - 4. It was observed for Ibadan based on the outcome of the analysis that the Jensen-Haise model has the highest correlation with the FAO56-PM model with r=0.804 followed by the Priestly-Taylor model with r=0.725, the BMN model with r=0.706 and the Hargreaves-Samani model with r=0.672. But taking into consideration the values obtained from the other statistical parameters applied, the BMN model produced the best estimate followed by the Jensen-Haise model, this was closely followed by the Hargreaves-Samani model which was a modification of the Hargreaves model developed for grass conditions (Alexandris *et al*. 2008) and the Priestly-Taylor model.

At Kano, the r values obtained are 0.636 for BMN, 0.42 for Jensen-Haise, 0.456 for Hargreaves-Samani and 0.066 for Priestly Taylor. The BMN model also produced the best estimates considering the results of other parameters used for the statistical analysis as well as the correlation (r) values which corroborate the claim by Duru (1984) that the BMN model is best for the Nigerian condition. Jensen Haise model generated the next best estimates, followed by the Hargreaves-Samani model with the Priestly-Taylor model having the worst estimates as reflected by the r value of 0.066. This outcome supports the claim of Priestly and Taylor (1972) that the model is developed for regions having low moisture stress.

The models have the following r values for Onne, BMN – 0.723, Jensen-Haise – 0.735, Hargreaves-Samani – 0.709 and Priestly-Taylor – 0.686. With the outcomes obtained from the MBE, $S^2d$, MAE and RMSE, the BMN model gave the best estimates, the Jensen-Haise model produced the second best estimates, followed by the Priestly-Taylor and the Hargreaves-Samani models in that order. The Priestly Taylor model outperformed the Hargreaves-Samani model because the climatic characteristic of the region favours the model whereas the Hargreaves-Samani model is more suitable in grass conditions (Alexandris *et al*. 2008).

The models were also checked for either overestimating or underestimating $ET_o$ values by finding the difference in their estimates from estimates obtained from the FAO56-PM model on an annual basis. The BMN model has the highest over estimation of 12.33mmday$^{-1}$ and the lowest underestimation value of 1.29mmday$^{-1}$ in Ibadan, Hargreaves-Samani did not underestimate but its overestimation ranged from 15.33mmday$^{-1}$ and 2.40mmday$^{-1}$, Priestly-Taylor model did not also underestimate and its overestimation ranged from 49.77mmday$^{-1}$ to 30.28mmday$^{-1}$ while the Jensen-Haise model underestimated through all the years considered for this study, with its values ranging from 10.58mmday$^{-1}$ to 24.49mmday$^{-1}$. (Figure 1)

For Kano, both the BMN and Hargreaves-Samani models overestimated through all the years. Their values ranged between 1.29mmday$^{-1}$ to 41.87mmday$^{-1}$ and 14.90mmday$^{-1}$(mm) to 68.24mmday$^{-1}$ respectively. The Priestly-Taylor has a maximum overestimation of 12.49mmday$^{-1}$ and a maximum underestimation of 31.87mmday$^{-1}$ while the Jensen-Haise has a maximum overestimation of 7.01mmday$^{-1}$ and a maximum underestimation of 38.85mmday$^{-1}$ (Figure 2)

In onne, all the models used for the study overestimated $ET_o$ values except the Jensen-Haise model which produced an underestimation. The BMN, Hargreaves-Samani and Priestly-Taylor overestimations ranged from 3.32mmday$^{-1}$ to 15.05mmday$^{-1}$, 29.43mmday$^{-1}$ to 49.72mmday$^{-1}$ and 1.80mmday$^{-1}$ to 13.41mmday$^{-1}$ respectively. The Jensen-Haise model only produced underestimations which ranged from 13.89mmday$^{-1}$ to 25.95mmday$^{-1}$. (Figure 3)

From the above results, it was seen that the Jensen-Haise method under predicted $ET_o$ values in all the locations. This makes it a poor estimator of $ET_o$ in these locations because according to Duru (1984), “from a design and safety standpoint, a model that over predicts should be preferred to one that under predicts”.

 

The other three models over predicted $ET_o$ values across the locations and these makes them better estimators than the Jensen-Haise model, however, of the three models the BMN can be considered to be the best estimator of $ET_o$ in Nigeria because it over predicts $ET_o$ to a lesser degree than the other model which also supports the statement by Duru (1984) that for economic considerations there should be a practical limit to acceptable over prediction thus making the model that over predicts to a lesser degree a better model. It also outperformed the other models when the statistic analyses were carried out.

## 4. Conclusion

Meteorological data were obtained from IITA stations in Ibadan, Kano and Onne in Nigeria. These data were used to estimate $ET_o$ values using the FAO56-PM model, BMN, Hargreaves-Samani model, Priestly-Taylor model and the Jensen-Haise model. Estimates from the final four models were compared with estimates from FAO56-PM model using statistical parameters.

Results obtained from the analysis carried out showed different degrees of variation and correlation between the FA56-PM and the other four evapotranspiration models but in all, the BMN model proved to be the next best model for evaluating $ET_o$. This is made so because it is well correlated with the $ET_o$ estimates in FAO56-PM, requires less volume of data for its application (the region of study is not rich in data) and the ease of its use.

In conclusion it could be said that the BMN model could be utilized for accurate and consistent estimates of $ET_o$ in Nigeria

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Table 1: Parameters required by each model for the estimation of $ET_o$

| **Method** | FAO-56 **(Standard)** | Blarney-Morin-Nigeria | Hargreaves-Samani | Priestly-Taylor | Jensen Haise |
|---|---|---|---|---|---|
| APPROACH | Combination | Temperature | Radiation | Radiation | Temperature |
| Variables | | | | | |
| Temperature (°C) | ✓ | ✓ | ✓ | - | ✓ |
| Humidity (%) | ✓ | ✓ | - | ✓ | - |
| Wind speed ($ms^{-1}$) | ✓ | - | - | - | |
| Solar Radiation (MJ $m^{-2}$ $day^{-1}$) | ✓ | - | ✓ | ✓ | |
| Extra-terrestrial radiation (MJ $m^{-2}$ $day^{-1}$) | ✓ | ✓ | ✓ | ✓ | - |
| Sunshine Duration (hr) | - | - | - | ✓ | - |
| Saturated vapour pressure (kPa) | ✓ | - | - | - | - |
| No of parameters Reqd. | 6 | 3 | 3 | 4 | 1 |

Table 2: Summary of evaluation statistics of four evapotranspiration models at Ibadan

| **Statistical Parameters** | **MODELS** | | | |
|---|---|---|---|---|
| | **Jensen-Haise** | **BMN** | **Hargreaves-Samani** | **Priestly Taylor** |
| **MBE** | **1.833(3)** | **0.338 (1)** | **0.695 (2)** | **3.418 (4)** |
| **$S^2d$** | **0.207(1)** | **0.264 (3)** | **0.231 (2)** | **0.598 (4)** |
| **MAE** | **1.834(3)** | **0.470 (1)** | **0.739 (2)** | **3.418 (4)** |
| **RMSE** | **1.888(3)** | **0.470 (1)** | **0.502 (2)** | **3.199 (4)** |
| ***R*** | **0.804(1)** | **0.706 (2)** | **0.672 (4)** | **0.725 (3)** |
| **Average Rank** | **(2)** | **(1)** | **(3)** | **(4)** |

*Rank Values are given in parenthesis. 1 indicating model results closest to FAO56-PM & 4 indicating model results farthest to FAO-56 (MBE - Mean Bias Error; $S^2d$- Measurement of the variability of the difference between the predicted and observed values; MAE - Mean Absolute Error; RMSE - Root Mean square error and r - Correlation Coefficient)*

Table 3: Summary of evaluation statistics of four evapotranspiration models at Kano

| **Statistical Parameters** | **MODELS** | | | |
|---|---|---|---|---|
| | **Jensen-Haise** | **BMN** | **Hargreaves-Samani** | **Priestly Taylor** |
| **MBE** | **1.732(3)** | **1.191 (1)** | **3.085 (4)** | **1.318 (2)** |
| **$S^2d$** | **1.970(2)** | **1.563 (1)** | **2.956 (4)** | **2.771 (3)** |
| **MAE** | **1.825(4)** | **0.879 (1)** | **1.206 (2)** | **1.334 (3)** |
| **RMSE** | **2.228(3)** | **1.726 (1)** | **3.531 (4)** | **2.121 (3)** |
| ***R*** | **0.421(3)** | **0.636 (1)** | **0.456 (2)** | **0.066 (4)** |
| **Average Rank** | **(2)** | **(1)** | **(4)** | **(3)** |

*Rank Values are given in parenthesis. 1 indicating model results closest to FAO56-PM & 4 indicating model results farthest to FAO-56 (MBE - Mean Bias Error; $S^2d$- Measurement of the variability of the difference between the predicted and observed values; MAE - Mean Absolute Error; RMSE - Root Mean square error and r - Correlation Coefficient)*

Table 4: Summary of evaluation statistics of four evapotranspiration models at Onne

| **Statistical Parameters** | **MODELS** | | | |
|---|---|---|---|---|
| | **Jensen-Haise** | **BMN** | **Hargreaves-Samani** | **Priestly Taylor** |
| **MBE** | **1.998(3)** | **0.728 (1)** | **3.421 (4)** | **0.748 (2)** |
| **$S^2d$** | **0.150(1)** | **0.230 (4)** | **0.571 (3)** | **0.168 (2)** |
| **MAE** | **1.998(3)** | **0.734 (1)** | **3.425 (4)** | **0.775 (2)** |
| **RMSE** | **2.035(3)** | **0.871 (1)** | **3.503 (4)** | **0.852 (2)** |
| ***R*** | **0.735(1)** | **0.723 (2)** | **0.709 (3)** | **0.686 (4)** |
| **Average Rank** | **(2)** | **(1)** | **(4)** | **(3)** |

 

*Rank Values are given in parenthesis. 1 indicating model results closest to FAO56-PM & 4 indicating model results farthest to FAO-56 (MBE - Mean Bias Error; $S^2d$- Measurement of the variability of the difference between the predicted and observed values; MAE - Mean Absolute Error; RMSE - Root Mean square error and r - Correlation Coefficient)*

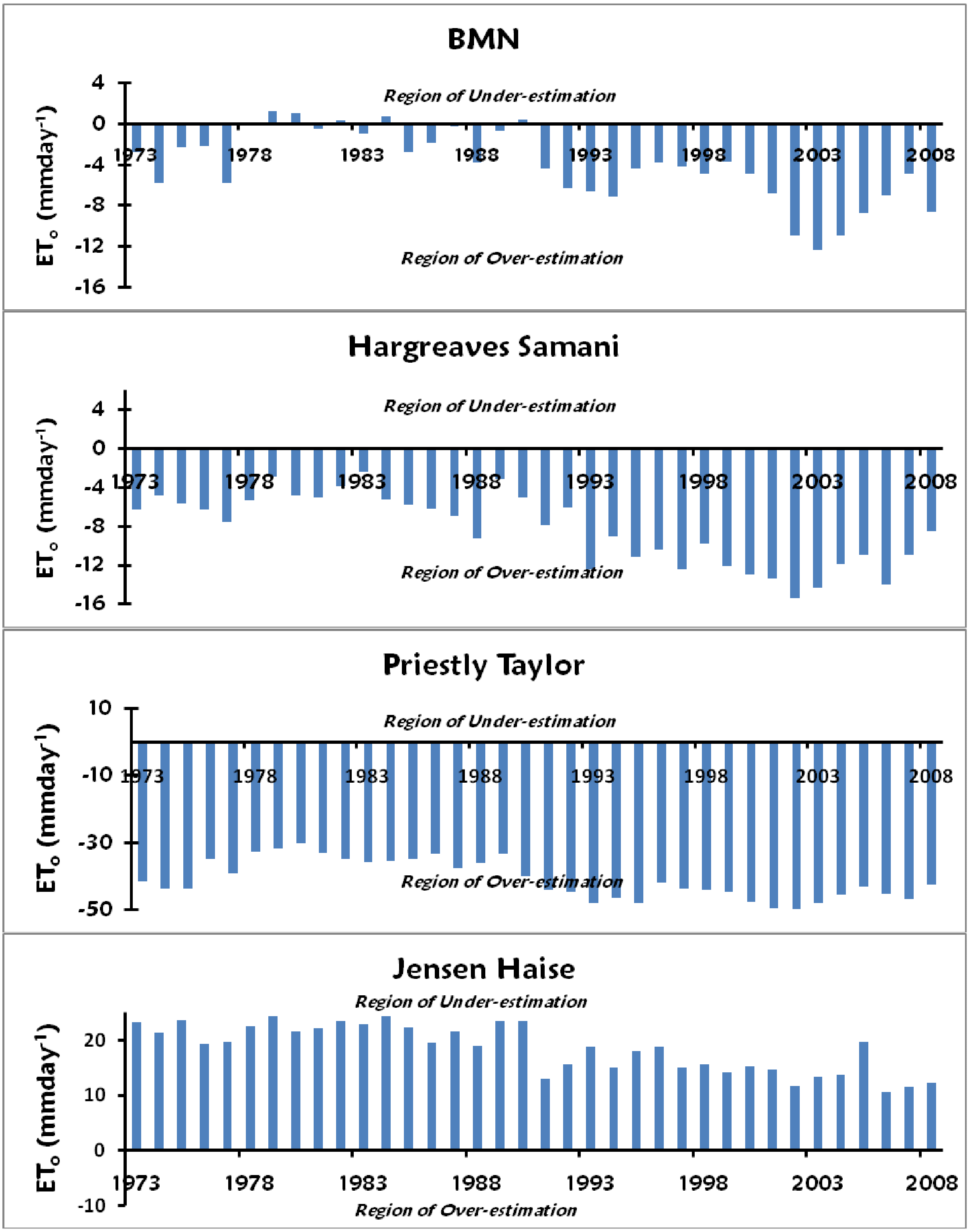


Figure 1: *Annual Estimation difference between FAO56-PM $ET_o$ values and the values from the other Models for Ibadan.*

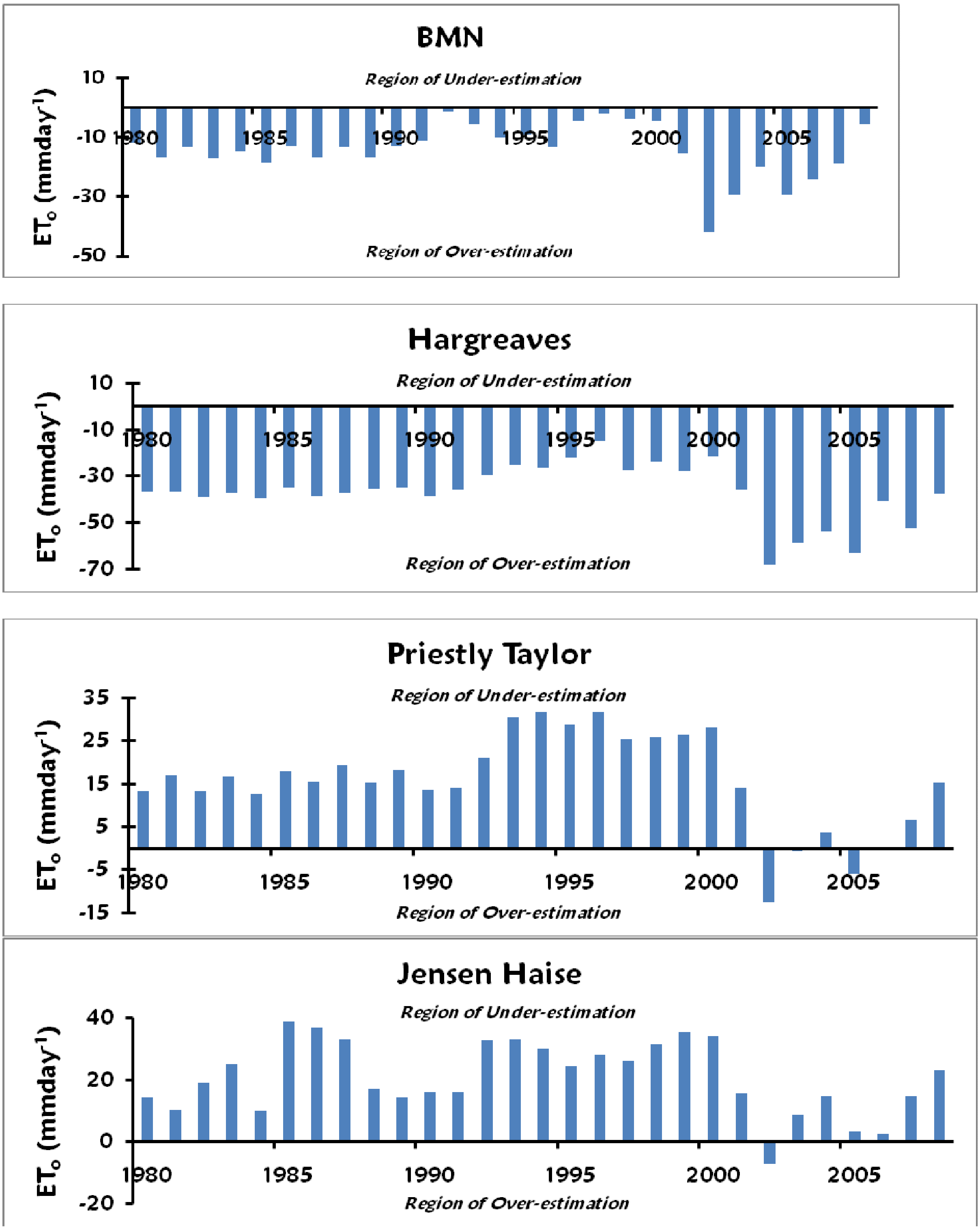


Figure 2*: Annual Estimation difference between FAO56-PM $ET_o$ values and the values from the other Models for Kano.*

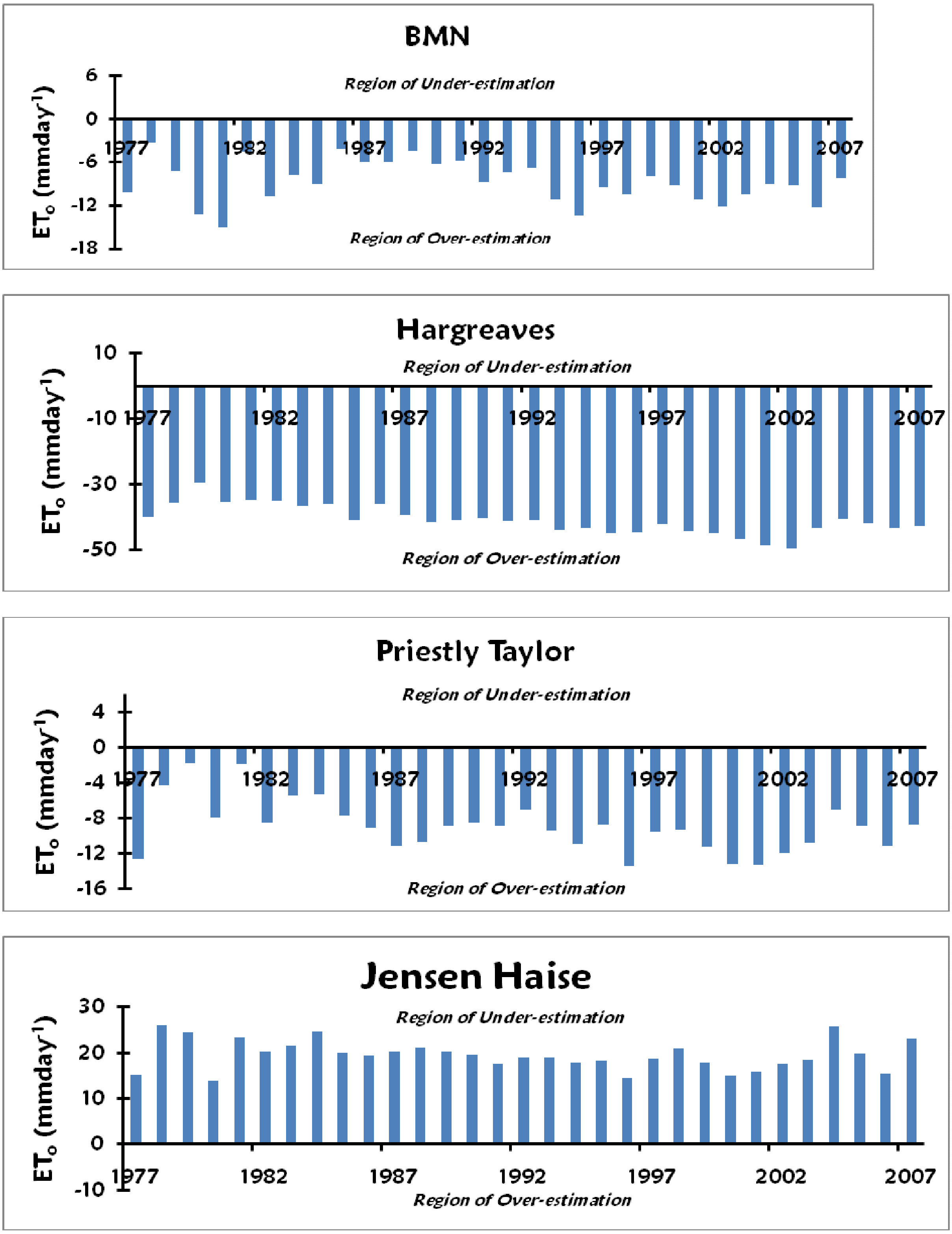


Figure 3*: Annual Estimation difference between FAO56-PM $ET_o$ values and the values from the other Models for Onne.*