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ESTIMATION OF EVAPOTRANSPIRATION WITH FAO-56 PENMAN-MONTEITH EQUATION FOR THREE AGROECOLOGICAL ZONES OF NIGERIA

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ABSTRACT

The Food and Agriculture Organisation (FAO) irrigation and drainage Paper 56 recommends the use of Penman-Monteith (*PM*) method for calculating reference evapotranspiration (ET_o). This method has been widely accepted. Alternative methods recommended where data requirements for the *PM* cannot be met are Hargreaves (*HG*) and pan methods. Therefore, this study was carried out to evaluate ET_o with the *PM* method and develop its relationship with *HG* and pan methods for Onne (humid), Ibadan (sub-humid) and Kano (semi-arid), Nigeria using 1990-2005 daily climatic data. The data were resolved to daily means of each week of the year, and monthly and annual totals. Deviations of the data from long-term means were determined and the ET_o methods were compared using root mean square error (*RMSE*) and mean bias error (*MBE*). Autocorrelation coefficients and regression analysis were also carried out. The daily means for each week with *PM* ET_o ranged from 2.39-3.82 mm in Onne, 2.45 -4.48 mm in Ibadan and 3.62-7.92 mm in Kano. Mean annual *PM* ET_o was 1130 mm vs. 2450 mm of rainfall in Onne; 1249 mm in Ibadan vs. 1286 mm of rainfall and 2007 mm in Kano vs. 786 mm of rainfall. The *HG* method over-predicted *PM* ET_o in Onne and Ibadan and under-predicted it in Kano. The pan method under-predicted it in Onne and Ibadan. Nonetheless, the *HG* method was a better estimator of *PM* ET_o in Kano than Onne and Ibadan, although daily means in the dry season were more variable. Daily means of *PM* ET_o were significantly related to means *HG* ET_o ($P < 0.0001$, r^2 from 0.72-0.93) and pan ET_o ($P < 0.0001$, r^2 from 0.91-0.93). Autocorrelation lengths of annual ET_o ranged from 2-2.8 years, suggesting a period of about 3 years of temporal dependence. The study showed that apart from the differences in magnitude of ET_o, trends of *PM*, *HG* and pan methods were similar, particularly for daily means and monthly totals. Therefore, the regression equations developed in this study can be used to estimate *PM* ET_o for similar climatic zones where the data requirements cannot be met but data for *HG* or pan method are available.

INTRODUCTION

The Food and Agriculture (FAO) irrigation and drainage Paper 56 (Allen et al., 1998) in which the modified Penman-Monteith (*PM*) method is recommended for the evaluation of reference evapotranspiration (ET_o) has been widely adopted. Alternative methods to the *PM* method that were recommended are the Hargreaves (*HG*) and pan methods, for places where the data required for the *PM* method are not available. Reference evapotranspiration is the evapotranspiration rate from a reference surface of a hypothetical grass not short of water. The data required for the *PM* method are radiation, air temperature, air humidity and wind speed. These data are very difficult to obtain in many countries, particularly developing nations, making the adoption of models such as the *HG* method that requires mainly temperature data (Droogers and Allen, 2002) or pan method that requires only pan evaporation data more attractive. Even for the calculation of ET_o using *PM*, it is envisaged that some basic data will be missing or not available and substitutes have to be used (Allen et al., 1998).

Evapotranspiration data are needed for efficient management of irrigation systems, understanding of the hydrologic cycle and water balance, and its influence on climate change (Yu et al., 2002; Hsiao et al., 2007; Paltineanu et al., 2007). Direct measurements are, however, very costly and difficult, hence the need to rely on climatological data to obtain ET_o.

Droogers and Allen (2002) stated that one advantage of the *PM* method over many other methods is that it is a predominantly physically-based method. Allen et al. (1998), and Droogers and Allen (2002) stated that the *HG* method under-predicts ET_o calculated by *PM* method under high wind condition (dry condition) and over-predicts it under a relative high humidity (wet conditions). Hess (1998) compared the *PM* method with some other methods in northeast Nigeria and found that the PM method was better than the other methods. However, Hess (1995), using 1961-1990 data, used daily means of each month and substituted sunshine duration for solar radiation.

Thus, obtaining the exact basic data for the *PM* method in particular or any method in general, is often difficult in a developing nation like Nigeria (Hess, 1998; Chineke et al., 1999; Droogers and Allen, 2002). Therefore, this study was carried out due to the fact that reliable basic data on solar radiation, air temperature, air humidity and wind speed were available on daily basis from 1990-2005 for 3 contrasting agroecological zones (humid, sub-humid and semi-arid) of Nigeria. Allen et al. (1998) suggested that the *HG* method should be verified in regions with complete set of data for calculation of *PM* reference evapotranspiration. The aims of the study were (i) to evaluate reference evapotranspiration using the *PM*, *HG* and pan methods for the agroecological zones, and (ii) to determine its variation with methods of calculation, location and time.

MATERIALS AND METHODS

Data collection and calculation of reference evapotranspiration

Meteorological data, spanning the period 1990-2005, were collected from the Agrometeorological and Crop Modeling Unit of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria for the stations at Onne (latitude 4.717 ^{o}N, longitude 7.175 ^{o}E) in the humid zone, Ibadan (latitude 7.388 ^{o}N and longitude 3.896 ^{o}E) in the sub-humid zone and Kano (latitude 11.996 ^{o}N and longitude 8.517 ^{o}E) in the semi-arid zone. Onne has a forest vegetation; Ibadan is in the derived savanna while Kano in the Sudan-Sahelian savanna. Data collected for each location were daily rainfall (mm), pan evaporation (mm), wind speed (km h^{-1}), solar radiation (MJ m^{-2} day^{-1}), minimum and maximum temperature (^{o}C), minimum and maximum relative humidity (%). However, the pan evaporation data for Kano were not used in this study while the lack of wind speed data at this location in 1990 led to the non-calculation of ET_o with the *PM* method for this year. Overall, there were 306-366 days (mean = 363 days, standard deviation = 9 days) of data input for each year in this study.

Reference evapotranspiration was calculated using the FAO-56 guidelines for *PM*, *HG* and pan methods (Allen et al., 1998). The *PM* method was calculated with the following equation:

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

where,

ET_o is reference evapotranspiration (mm day^{-1}),

R_n is net radiation at the crop surface (MJ m^{-2} day^{-1}),

G is soil heat flux density (MJ m^{-2} day^{-1}),

T is mean daily air temperature at 2 m height (°C),

u_2 is wind speed at 2 m height (m s^{-1}),

e_s is saturation vapor pressure (kPa),

e_a is actual vapor pressure (kPa),

$e_s - e_a$ is saturation vapor pressure deficit (kPa),

Δ is slope vapor pressure curve (kPa °C^{-1}),

γ is psychrometric constant (kPa °C^{-1}).

The Hargreaves (*HG*) method was calculated with the following equation:

$$ET_o = 0.0023(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5}\,R_a \quad (2)$$

where,

T_{mean}, $T_{max.}$ and T_{min} are mean, maximum and minimum temperatures (^{o}C)

R_a is extraterrestrial radiation (MJ m^{-2} day^{-1}), which is converted to equivalent evaporation in mm day^{-1} with a factor of 0.408.

The pan evaporation method was calculated as follows:

$$ET_o = K_p\,E_{pan} \quad (3)$$

where,

ET_o *is* reference evapotranspiration (mm day^{-1}),
K_p is pan coefficient,
E_{pan} is pan evaporation (mm day^{-1}).

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Data analysis

The daily data were resolved into weeks and months of each year after which they were subjected to descriptive statistics (means, standard deviation, sum and range) using STATISTIX (Analytical Software, 1998). From these data, water deficit was calculated as the difference between rainfall and ET_o while aridity index was obtained as the ratio of rainfall to ET_o (Paltineanu et al., 2007). Analysis of variance was carried out to compare the methods for the different locations.

The normalized deviations (Servat et al., 1997; Paturel et al., 1997) of ET_o from the long-term mean (i.e., overall mean of for daily values of each week or monthly and annual totals) were obtained as follows:

$$\text{Normalized deviation} = (x_i - \mu)/s \qquad (4)$$

where,

x_i = daily mean of each week (weeks 1-52), or monthly total or annual total of ET_o

μ = long-term mean (1990-2005) of either the daily, monthly or annual ET_o

s = standard deviation of either the daily, monthly or annual ET_o

Temporal dependence (Nielsen and Wendroth, 2003) of ET_o was also determined by calculating autocorrelation functions using GenStat (Lawes Agricultural Trust, 2005). The degree of temporal dependence (autocorrelation lengths) was determined using interpolation at an autocorrelation coefficient of 0.368, as suggested by Nielsen and Wendroth (2003).

The different methods were compared using ET_o calculated by PM method as standard for calculation of root-mean square error ($RMSE$):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (ET_{o\text{-estimated}} - PM)^2}{N}} \qquad (5)$$

where,

$ET_{o\text{-estimated}}$ is the ET_o calculated by using HG or pan method

N is the number of data pairs or observations.

The mean bias error (MBE) was calculated as:

$$MBE = \frac{\sum_{i=1}^{N} (ET_{o\text{-estimated}} - PM)}{N}$$

Regression analysis was also carried out between the methods, to develop predictive equations for PM from HG or pan data.

RESULTS AND DISCUSSION

Climatic variations in the agroecological zones

Annual solar radiation (Table 1) was significantly higher in Kano (7377 MJ m^{-2}) than Ibadan (5386 MJ m^{-2}) and Onne (4781 MJ m^{-2}) (least significant difference at 5% probability level, $LSD_{0.05}$ = 554 MJ m^{-2}). Annual pan evaporation ranged from 1059-1281 mm in Onne whereas it ranged from 1167-1693 mm in Ibadan (Table 1). Daily mean wind speed for weeks 1-52 (i.e., January-December ranged from 2.45-3.9 km h^{-1} in Onne, 1.95-4.30 km h^{-1} in Ibadan and 2.75-10.47 km h^{-1} in Kano. Thus, the differences in the climatic parameters of the agroecological zones were more obvious with cumulative or annual data than with daily means.

Rainfall and reference evapotranspiration

Daily means of rainfall on weekly basis showed the unimodal distribution of rainfall in Onne and Kano and the bimodal distribution of rainfall in Ibadan (Fig. 1). Furthermore, ET_o by *PM* method was over-predicted by the *HG* method and under-predicted by pan method in Ibadan and Onne whereas *PM* and *HG* were similar for about 38 weeks out of 52 in Kano. For Onne, mean daily values for rainfall ranged from 0.45-15.14 mm; *PM* ET_o ranged from 2.39-3.82 mm, *HG* ET_o from 3.28-4.98 mm and pan ET_o from 1.70-3.18 mm. For Ibadan, mean daily rainfall ranged from 0.01-9.61 mm; *PM* ET_o from 2.45-4.48 mm, *HG* ET_o from 3.52-5.77 mm and pan ET_o from 1.53-3.96 mm. Mean daily rainfall in Kano ranged from 0-9.76 mm; *PM* ET_o from 3.62-7.92 mm and *HG* ET_o from 4.39-7.04 mm.

Monthly totals of rainfall and ET_o followed the same pattern as daily means of each week (Fig. 2).

Mean monthly rainfall in Onne ranged from 24-420 mm; 5-219 mm in Ibadan and 0-259 mm at Kano. Mean monthly *PM* ET_o values ranged from 76-113 mm in Onne; 79-136 mm in Ibadan and 127-213 mm in Kano. Thus, using the *PM* method, there was a water deficit of 66 mm in December, 80 mm in January and 60 mm in February in Onne. In Ibadan, water deficits of 69-102 mm were observed from November-December, and January-March. In Kano, only July and August had water surplus of 68-132 mm. The remaining months had water deficits that ranged from 7-212 mm.

Annual totals of rainfall and ET_o (Fig. 3) showed that variations were not as smooth as the trends obtained with daily or monthly means. The annual totals, however, showed the distinctions among the agroecological zones better, with rainfall > than ET_o in the humid zone, rainfall ≡ ET_o in the sub-humid zone and rainfall < ET_o in the semi-arid zone.

The trends among the ET_o models were similar to those observed for daily and weekly data. The annual *PM* tended to be relatively low in Kano between 2001 and 2005 because of low wind speed values. Based on the *PM* method, aridity index for Onne was 2.17; it was 1.04 and 0.42 for Kano. Although, the observations in this study (Figs. 1-3) clearly support the observation by Allen et al. (1998) that the *HG* method over-predicts the *PM* method under relatively high humidity (i.e., Onne), the under-prediction expected under high wind condition as in Kano was not clearly expressed until annual values were used. Ibadan, a sub-humid zone conformed to the trend expected for the very humid zone.

The distribution of rainfall (Fig.1-3), and how well it can be managed to maximize yield even when dry spells occur (Oluwasemire et al., 2002) are crucial issues in all the ecological zones. Therefore, adoption of appropriate soil and water conservation practices remain a major guarantee for yield maximization. Rockström and Barron (2007) noted that farmers' perception in the semi-arid or savanna regions is often tilted to risk minimization rather than the adoption of appropriate soil and water management practices to achieve yield maximization.

Comparison of methods

The order of *RMSE* values varied between Kano and Onne, depending on whether daily, monthly or annual values were used to compare *PM* and *HG* ET_o (Table 2). The *HG* was a better estimator of *PM* in Kano than Onne and Ibadan with daily mean and monthly totals of ET_o. The pan method also had lower *RMSE* values than the *HG* method at Onne and Ibadan. It was, therefore, a better estimator for *PM* ET_o in the humid zone compared to *HG* ET_o though it had a tendency to under-predict as shown by the *MBE* values. The *RMSE* between the *PM* and pan method was lower at Ibadan than Onne, irrespective of time-scale of measurement (Table 2).

The *MBE* values confirmed further that *HG* over-predicted (positive values) *ETo* obtained by *PM* in Ibadan and Onne and under-predicted (negative values) it in Kano, with Kano having daily means *HG* values almost similar to *PM* daily means (Fig. 1-3). Allen et al. (1998), Hess (1998) reported *RMSE* values of 0.33 mm day^{-1} for *PM* vs. Pristely-Taylor method, and 1.01 mm day^{-1} for Jensen and Haise method while other 4 methods used had a range of 1.39-1.69 mm day^{-1} in northeast arid zone of Nigeria. Thus, the FAO-56 *HG* and pan methods appeared more reliable than other models used by Hess (1998) against the *PM* ET_o in Nigeria.

Trends in reference evapotranspiration

Daily means of ET_o calculated with *PM*, *HG* and pan methods deviated from their long-term means with similar magnitudes (Fig. 4). This was, however, not the case for the annual sums. For the daily means, the normalized deviations for Onne were generally between -1 and 1 whereas those for Ibadan and Kano were between -1 and 2. The implication of the similarity in trends for the daily means is that it was only the magnitude of ET_o that differed significantly in the different climatic zone but at any point in time, changes in ET_o would reflect across the ecological zones, possibly with some lags among the zone. Such an observation had been made by Servat et al. (1997) and Paturel et al. (1997) with regards to the Sahelian drought of northern West Africa, which also affected the climate of coastal humid areas.

The variations observed on annual basis were caused by extreme events within years (i.e., excessively low or high values), which counterbalanced themselves on a long-term basis. Thus, a year with high ET_o within a period of 16 years could be counterbalanced by a year of low ET_o within the same period. This explains why there were shifts from location to location in terms of years with positive or negative normalized deviations. Using the *PM*, for example, at Onne, the sum of the negative normalized deviations was -5.76 (9 years) while that of the positive deviations (7 years) was 5.76. At Ibadan, the negative deviations (7 years) summed up to -6.19 whereas the positive deviations (9 years) were 6.18. For Kano, the negative deviations (6 years) summed up to -6.09 while the positive deviations (9 years) summed up to 6.09. Thus, although the magnitudes of the differences from long-term means counterbalanced each other, there were more years in which the need to cater for excessive evapotranspiration arose than for years with relatively low evapotranspiration. However, most of these years of high evapotranspirative demands occurred consecutively rather than being alternated with years of lower (than long-term mean) evapotranspiration in the 3 locations (Fig. 4). Water use efficiency by crops can be improved in years with high evapotranspirative demands by mulching, frequent but minimal supply of irrigation water and a number of other appropriate soil management options defined by local conditions (Hillel, 1998; Kirkham, 2005).

Autocorrelations significantly different from zero were observed at a lag (autocorrelation length) of 2 years for both *PM* and *HG* methods at Onne; a lag of 2.8 years for *PM* and 2 years for *HG* at Ibadan and a lag of 2.8 years for *PM* and 2.4 years for *HG* at Kano (Fig. 5). These lags indicate the extent of temporal dependence of ET_o at the various locations. They also suggest that trends in annual ET_o could only be expected to be similar for 2-3 previous and subsequent years at the 3 locations.

Regression between *PM* and other methods for the daily means obtained on weekly basis (Fig. 1) resulted in the following equations (N = 52):

Onne

$$PM = -0.189 + 0.782HG, \quad P < 0.0001,\ r^2 = 0.93 \tag{7}$$
$$PM = 0.847 + 0.954Pan, \quad P < 0.0001,\ r^2 = 0.93 \tag{8}$$

Ibadan

$$PM = -0.595 + 0.881HG, \quad P < 0.0001,\ r^2 = 0.91 \tag{9}$$
$$PM = 1.044 + 0.873Pan, \quad P < 0.0001,\ r^2 = 0.91 \tag{10}$$

Kano

$$PM = -1.730 + 1.327HG, \quad P < 0.0001,\ r^2 = 0.72 \tag{11}$$

where,

N = number of observations

PM, *HG* and *Pan* (in mm day^{-1}) have been previously defined,

P = probability level of significance, and

r^2 = coefficient of determination

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Although the *HG* method was a good estimator of *PM* daily means in Kano as shown by the *RMSE* and *MBE* values (Table 2), some variabilities especially from weeks 5-19, and 46-52 (Fig. 1) could not be explained by regression (r^2 values) as it could for Onne and Ibadan (Eqs. 7-11). There were no significant correlations between the annual sums of the ET_o models, except between *PM* and pan method at Onne (r^2 = 0.27, P = 0.018, N = 16). Stöckle et al. (2004) observed that there was no advantage of using 5-year data over 2-year data in developing the forms of Eqs. 7-11 between *PM* and *HG* methods. Given the autocorrelation lengths or temporal dependence of 2-2.8 years (Fig. 5), this observation appears applicable in this study but may not be valid with data exceeding 5 or 6 years.

CONCLUSION

Reference evapotranspiration (ET_o) obtained with Penman-Monteith (*PM*), Hargreaves (*HG*) and pan methods showed that the *HG* over-predicted the *PM* method in Onne (humid) and Ibadan (sub-humid) whereas it under-predicted it in Kano. There was more variation of data with annual sums than with daily means and monthly totals. Deviations of daily means from the long-term means indicated that it was only the magnitude of ET_o that differed significantly in the different climatic zones but at any point in time, changes in ET_o would reflect across the zones. There were more years with annual ET_o exceeding long-term means in Ibadan and Kano than Onne. Generally, the sub-humid zone was intermediate in trends to the semi-arid and humid zones. Both the daily means of the *HG* and pan methods correlated very significantly to the *PM* method in all the locations, making it possible to predict *PM* in areas where the data requirements cannot be met but *HG* and pan method data are available. Autocorrelation lengths of 2-2.8 years suggested that temporal dependence of data in a given year could only span a period of 4-6 years, with 2-3 previous and subsequent years being placed under consideration.

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Table 1: Annual evaporation and solar radiation in Onne, Ibadan and Kano, Nigeria between 1990 and 2005.

	Onne (Humid)		Ibadan (Sub-humid)		Kano (Semi-arid)
Years	Annual evaporation (mm)	Annual solar radiation (MJ m-2)	Annual evaporation (mm)	Annual solar radiation (MJ m-2)	Annual solar radiation (MJ m-2)
1990	1194	4679	1567	6207	7051
1991	1162	4827	1441	5292	8158
1992	1226	4886	1500	5271	7660
1993	1239	4711	1468	5099	8120
1994	1159	4576	1421	5502	7706
1995	1281	4500	1400	5465	7835
1996	1059	3961	1366	5333	8040
1997	1179	4852	1221	5226	7997
1998	1255	4766	1254	5425	8328
1999	1209	4557	1439	5304	7918
2000	1240	4217	1682	5349	8316
2001	1196	3934	1693	5258	7544
2002	1228	4828	1684	5186	5184
2003	1236	5829	1303	5191	4202
2004	1262	5767	1171	5250	7882
2005	1251	5614	1167	5819	6084

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Table 2. The root-mean square error (RMSE) and mean bias error (MBE) after comparing the reference evaporation models (Penman-Monteith, *PM*; Hargreaves, *HG* and pan) with data from Onne, Ibadan and Kano, Nigeria.

	RMSE (mm)		MBE (mm)	
Location	HG vs. PM	Pan vs. PM	HG vs. PM	Pan vs. PM
Daily means				
Onne	1.12	0.75	1.11	-0.74
Ibadan	1.15	0.72	1.14	-0.69
Kano	0.05	ND	-0.01	ND
Monthly totals				
Onne	25.31	17.81	18.66	-13.03
Ibadan	35.04	21.69	34.73	-21.06
Kano	13.82	ND	-1.43	ND
Annual totals				
Onne	392.51	295.81	378.26	-281.87
Ibadan	424.85	292.58	416.79	-252.68
Kano	419.18	ND	-18.28	ND

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Fig. 1. Daily means of rainfall and reference evapotranspiration (ET_o) in each week of the year from 1990-2005 in Onne, Ibadan and Kano, Nigeria.

Fig. 2. Monthly sums of rainfall and reference evapotranspiration (ET_o) from 1990-2005 in Onne, Ibadan and Kano.

Fig. 3. Annual sums of rainfall and reference evapotranspiration evapotranspiration (ET_o) from 1990-2005 in Onne, Ibadan and Kano.

Fig. 4. Normalized deviation of daily means and annual sums of reference evapotranspiration evapotranspiration (ET_o) from 1990-2005 in Onne, Ibadan and Kano.

Fig. 5. Autocorrelograms for annual reference evapotranspiration using Penman-Monteith (*PM*) and Hargreaves (*HG*) methods from 1990-2005 in Ibadan, Onne and Kano, Nigeria.

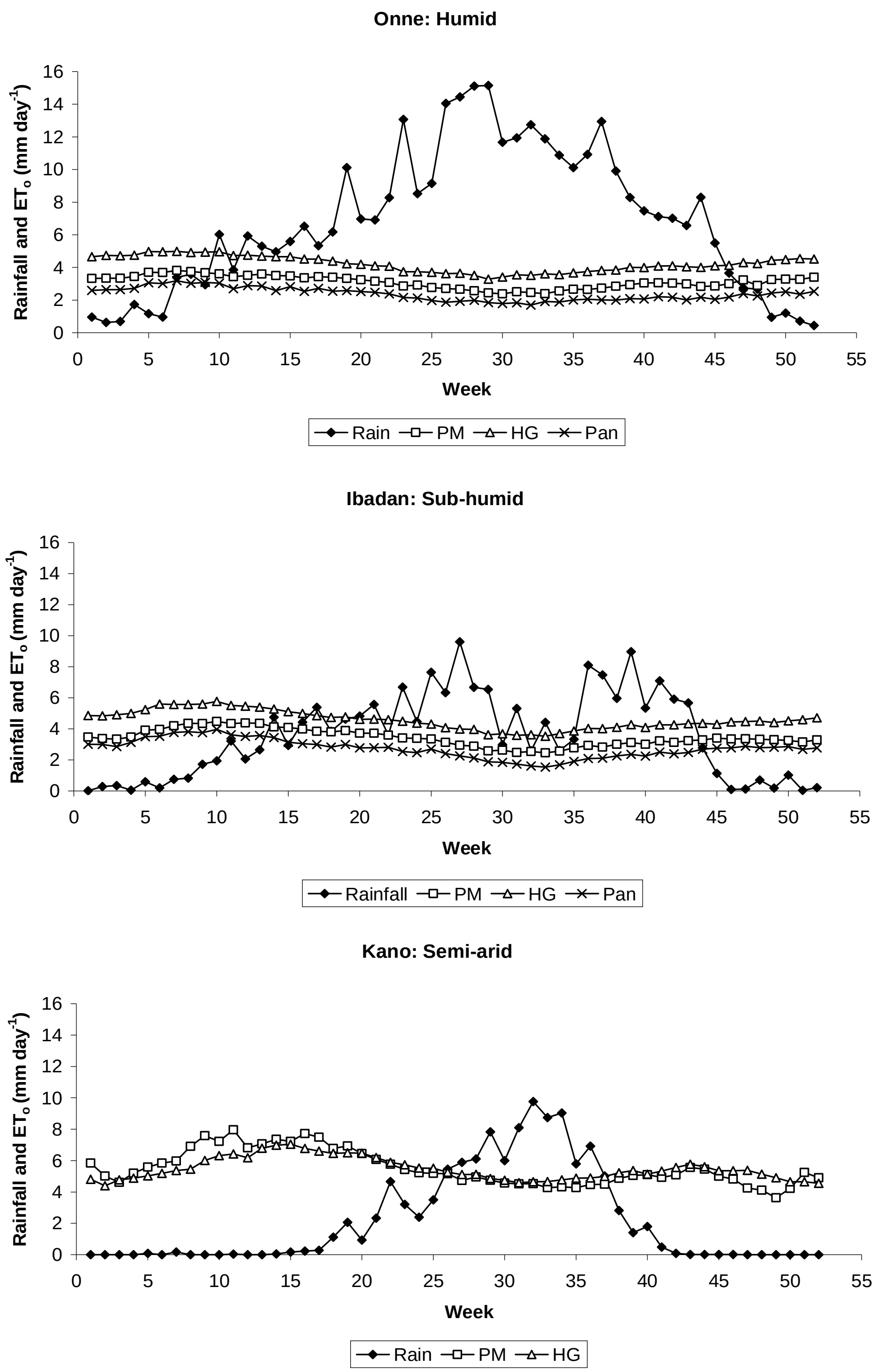
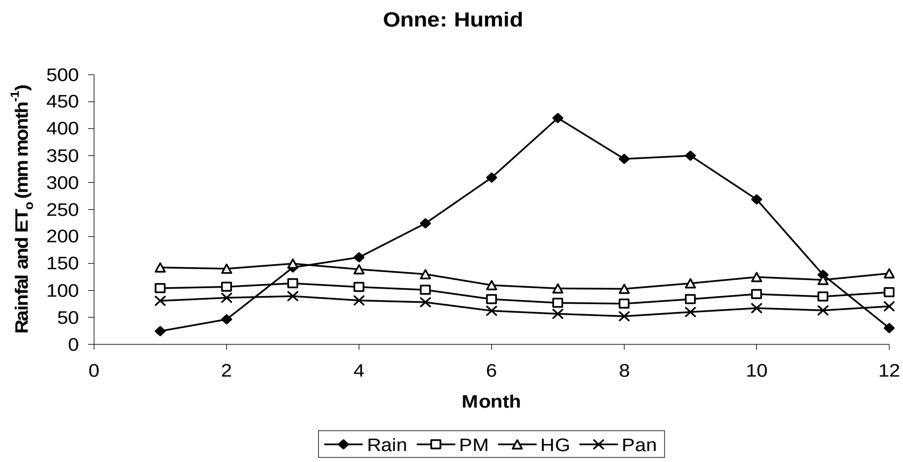
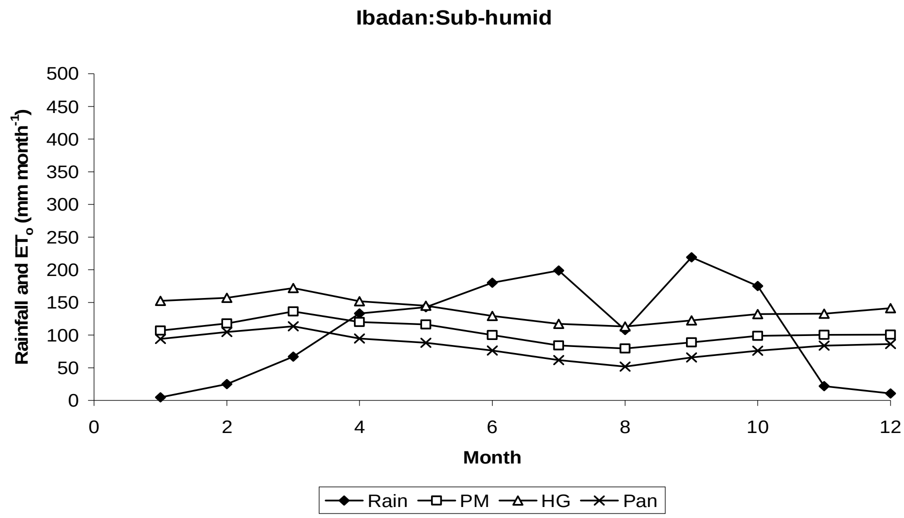

Onne: Humid
Rainfall and ET_o (mm day^{-1})
16
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
40
45
50
55
Week
Rain
PM
HG
Pan
Ibadan: Sub-humid
Rainfall and ET_o (mm day^{-1})
16
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
40
45
50
55
Week
Rainfall
PM
HG
Pan
Kano: Semi-arid
Rainfall and ET_o (mm day^{-1})
16
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
40
45
50
55
Week
Rain
PM
HG

Figure: 1.


Onne: Humid
Rainfall and ET$_o$ (mm month^{-1})
Month
Rain
PM
HG
Pan


Ibadan:Sub-humid
Rainfall and ET$_o$ (mm month^{-1})
Month
Rain
PM
HG
Pan

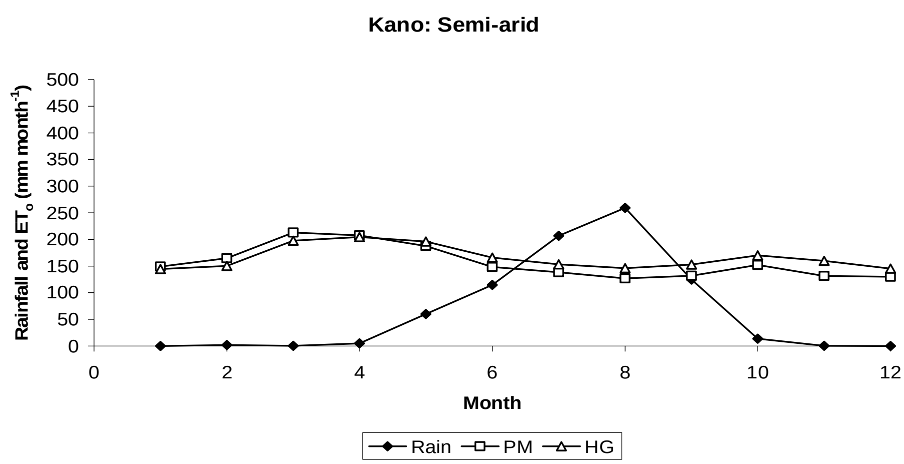

Kano: Semi-arid
Rainfall and ET$_o$ (mm month^{-1})
Month
Rain
PM
HG

Figure: 2.

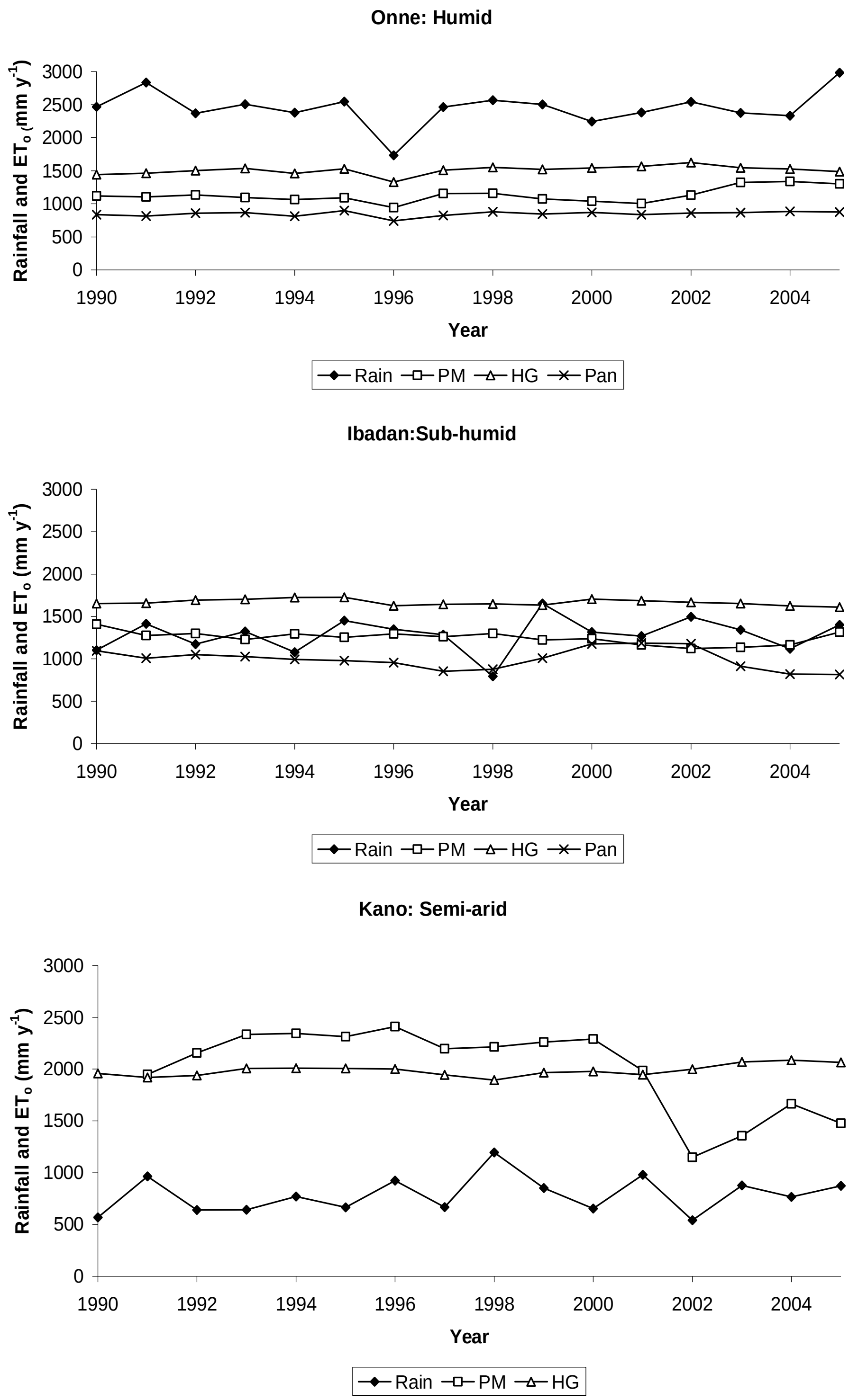

Onne: Humid
Rainfall and ET$_o$ (mm y^{-1})
3000
2500
2000
1500
1000
500
0
1990
1992
1994
1996
1998
2000
2002
2004
Year
Rain PM HG Pan
Ibadan:Sub-humid
Rainfall and ET$_o$ (mm y^{-1})
3000
2500
2000
1500
1000
500
0
1990
1992
1994
1996
1998
2000
2002
2004
Year
Rain PM HG Pan
Kano: Semi-arid
Rainfall and ET$_o$ (mm y^{-1})
3000
2500
2000
1500
1000
500
0
1990
1992
1994
1996
1998
2000
2002
2004
Year
Rain PM HG

Figure:3.

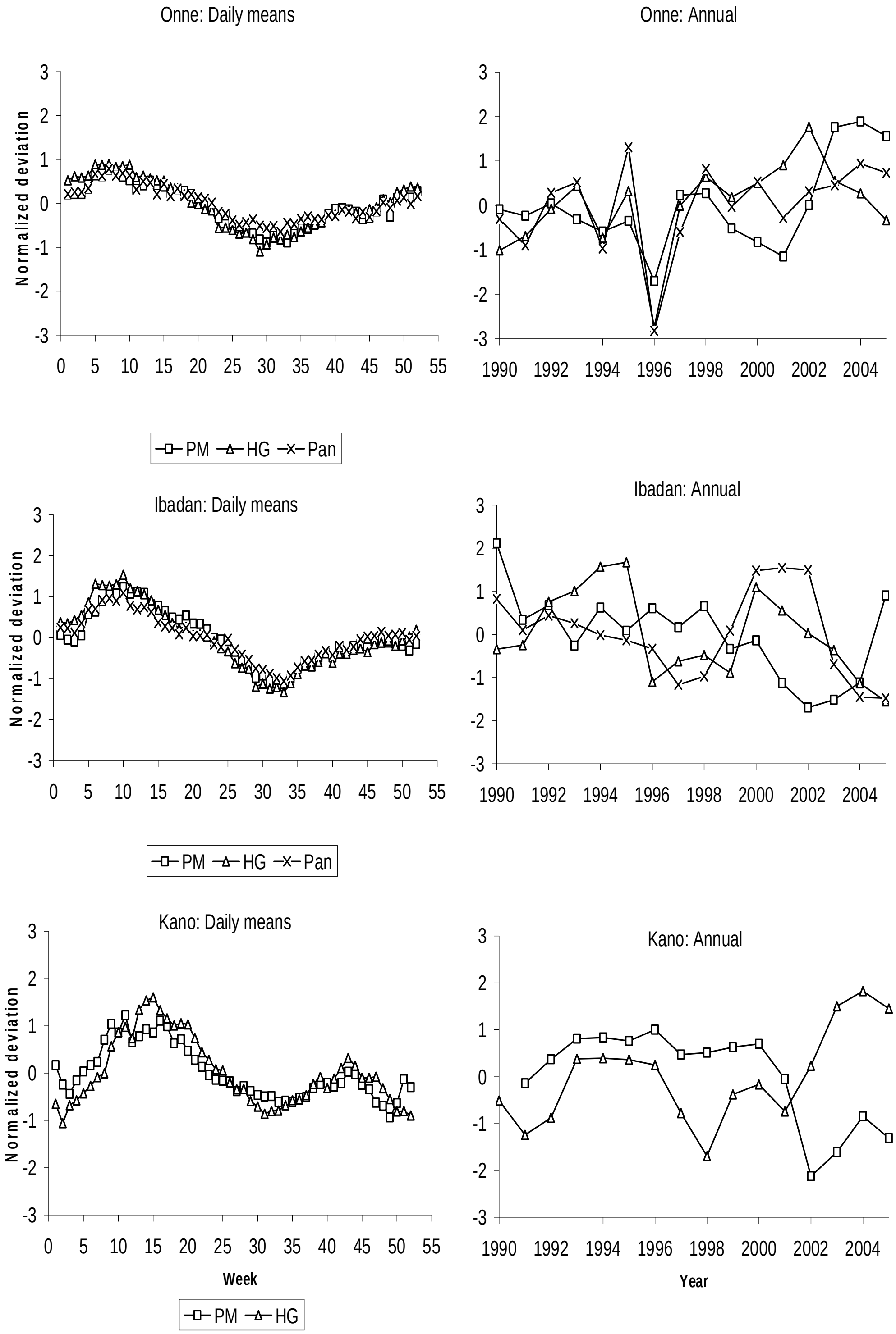

Onne: Daily means
Onne: Annual
Ibadan: Daily means
Ibadan: Annual
Kano: Daily means
Kano: Annual
Normalized deviation
Week
Year
PM HG Pan
PM HG Pan
PM HG

Figure: 4 .

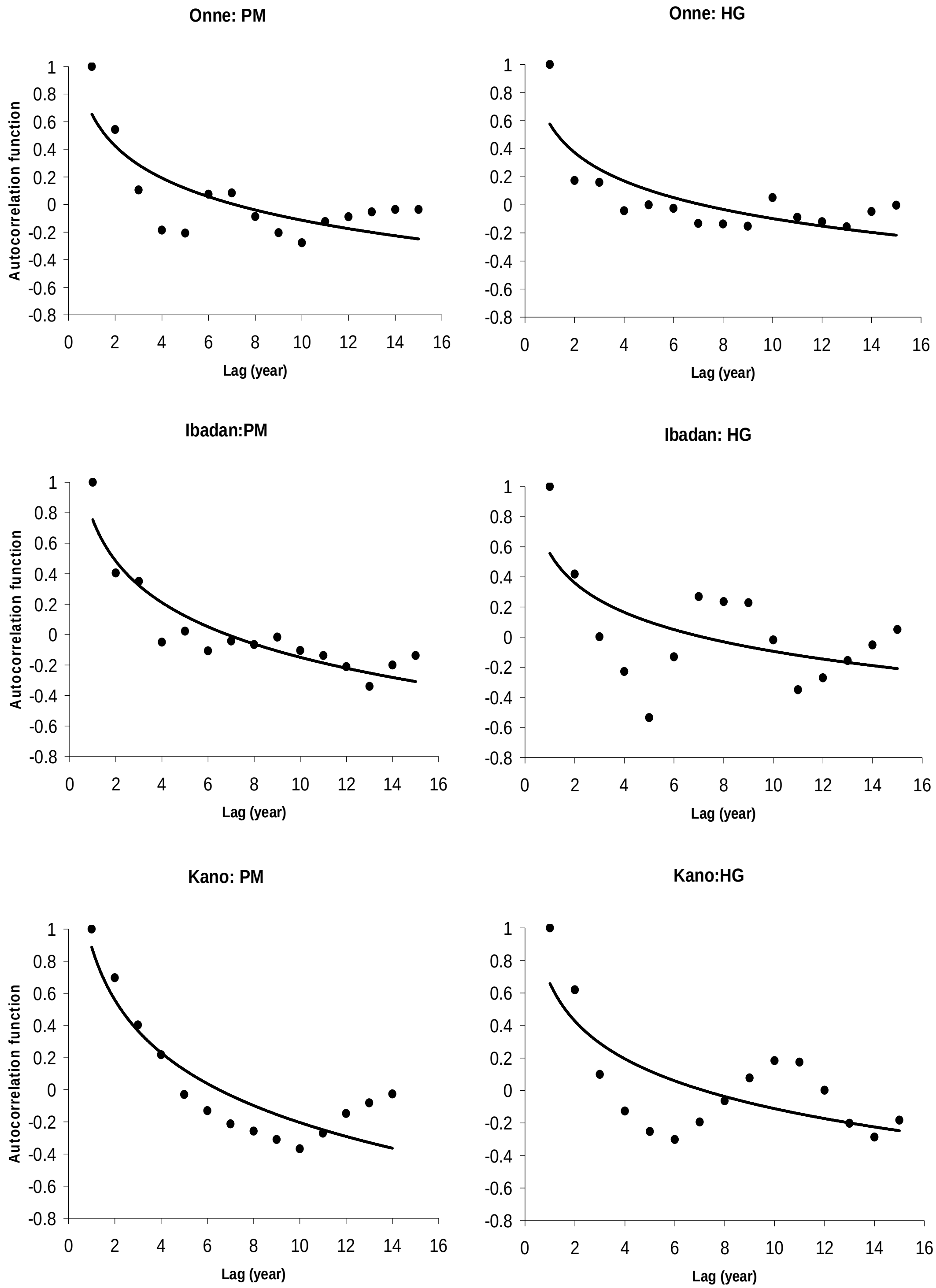

Onne: PM
Onne: HG
Ibadan:PM
Ibadan: HG
Kano: PM
Kano:HG
Autocorrelation function
Lag (year)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0
2
4
6
8
10
12
14
16

Figure: 5.