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TEMPORAL ANALYSIS OF EVAPOTRANSPIRATION USING FAO56PM EQUATION FOR THREE AGRO-ECOLOGICAL STATIONS IN NIGERIA

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ABSTACT: In this study, 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. Evapotranspiration rates for each of the stations were estimated using the FAO56-PM model. A non-parametric Mann-Kendal trend analysis was performed on the estimated ET_orates. The contributions of various meteorological variables (separation of the ET_o values into their Aerodynamic and Radiative parts) to the temporal trend detected in the reference evapotranspiration ET_o rates were ascertained to determine whether any or both parts are major determinants in the trend of ET_o at the three stations.The results obtained during the study showed that there was a significant decline in monthly and annual ET_o rates Ibadan ($P < 0.001$), a not significant decline in monthly and annual ET_o rates in Kano and a significant monthly and annual decline in ET_o rates for Onne ($P < 0.1$). The percentage annual decline for Ibadan, Kano and Onne were found to be 4.05%, 0.54% and 1.87% respectively. The study showed that the trend of estimated ET_o over Nigeria is towards the negative/decreasing direction.
Keywords: Evapotranspiration (ET_o), FAO56-PM Model, Mann – Kendall, Sen, IITA, Trend, Meteorological

1.INTRODUCTION

In normal environmental conditions, unavailability of water is a major factor limiting plant/crop growth and production. According to Wani et al. (2009), 95% of farmlands in Sub-Saharan Africa are rainfed and this allows for water deficit because rainfall water supply is never available in sufficient quantities all year round. Irrigation is an important aspect of crop management and planning which is usually adopted to cater for this water deficit. In irrigated/rainfed agriculture, it is of utmost importance to establish when and how much water to apply, and of course to determine the optimum sowing time to take advantage of the available soil moisture and precipitation; irrigation water is usually determined through evapotranspiration estimation procedures (Alexandris et al., 2008). Evaporation is the term used to describe water loss from water and bare-ground surfaces. It is a process by which moisture is converted into water vapour, removed and transported upwards into the atmosphere (Oguntunde, 1998). Transpiration also is the vapourisation of liquid water contained in plant tissues and the vapour being removed to the atmosphere. The loss of the water is usually through the stomata of plants and it's affected by parameters influencing evaporation and the crop's characteristics.

Evapotranspiration is the combination of these two processes and Ayoade (1988) describes about four sequential and distinct processes that takes place during evapotranspiration:

(i) Movement of water within the soil towards the ground surface or zone of absorption around the root of plants;
(ii) Transpiration;

(iii) Vapourisation of water at the soil at plant surface of the stomata of leaves; and
(iv) Removal and transport of the evaporated water, now in gaseous form, into the atmosphere.

The rate of evapotranspiration over any given surface is also dependent on the availability of moisture, if moisture is always available in sufficient quantities at the evapotranspirating surface, it will occur at the maximum rate possible.

The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ET_o. The reference surface is a hypothetical grass reference crop with specific characteristics (Allen et al. 1998). This was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. Allen et al. (1998) has recommended the FAO Penman-Monteith method as the sole method for determining ET_o, This method was selected because it takes into consideration the physical, physiological and aerodynamic properties of the location where it is used to estimate the ET_o of grass which was a close approximation.

The knowledge of evapotranspiration cannot be ignored by Agricultural, Irrigation and Drainage Engineers because the concept of evapotranspiration crops up in most research and development activities carried out by them. The increasing pressure on water resources requires a sound knowledge of where, when and how much water is used. This scenario makes evapotranspiration an important factor for evaluating water productivity and monitoring of irrigation performance (Mutiga et al. 2008).

A reliable estimate of Evapotranspiration (ET_o) is important in carrying out the estimation of irrigation water requirements and irrigation scheduling, reservoir design and development, crop modeling, agronomic studies,hydrological modeling, water resources planning and management (Hobbins et al., 2001a,b; Anayah, F. M. A, 2012); this informed the choice of the FAO-56 PM model for the estimation of evapotranspiration in this study.

This study assessed the evapotranspiration estimates for the three stations with the aim to determining the trajectory of its trend and also if the trajectory is caused by significant changes in aerodynamic and radiative parameters of the climate. The outcome will allow researchers and policy makers develop means of adaptation to cope with this changing so as to meet the evapotranspirative requirement for crops and other water related projects. The influence of rainfall on the trend of evapotranspiration in these stations was not independently determined.

2. MATERIALS AND METHODS

2.1. The Study Area

The area considered under this study covers the whole of Nigeria with specific emphasis on three cities, Ibadan, Kano and Onne where International Institute of Tropical Agriculture (IITA) stations are located. These locations are located in 3 different agro-ecological zones in Nigeria; Onne in the Southern Delta region having a humid climate characterized by swamps, heavy rainfall and mangrove forests, Ibadan is in the sub-humid climate which is characterized by rain forests and slightly heavy rainfall, Kano has a semi-arid or savannah climate characterized with scattered trees and shrubs.

2.2. 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_o using this approach, the equation stated below was applied and the computation of all required data necessary for the calculation of ET_o 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}], □-psychrometric constant [kPa °C^{-1}].

2.3. Temporal Analysis Procedure

The non-parametric Mann – Kendall test was also applied to detect the significance of the trend in the observed evapotranspiration values and the Sen's non-parametric test was applied using a linear model to detect the magnitude of the trend. The procedures followed were outlined by

Salmi, T. Et al. (2002).The temporal trend of estimated values of ET_o over the study duration was carried out using an excel template, MAKESENS, the combination of both Mann-Kendall test for trend and Sen's slope estimates. The Mann-Kendall test statistic S according to Salmi et al. (2002) is given by

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \quad (2)$$

where n is the length of the time series $x_i, \ldots, x_n$, and sgn(·) is a sign function, x_j and x_k are values in years j and k, respectively. The expected value of S equals zero for series without trend and the variance is computed as (Oguntunde et al. (2006)

The test statistic Z is then given as

$$\sigma^2(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5) \right] \quad (3)$$

Here q is the number of tied groups and t_p is the number of data values in pth group.

As a non-parametric test, no assumptions as to the underlying distribution of the data are necessary. The Z statistic is then used to test the null hypothesis, H_0 that the data is randomly ordered in time, against the alternative hypothesis, H_1, where there is an increasing or decreasing monotonic trend. A positive (negative) value of Z indicates an upward (downward) monotone trend. H_0 is rejected at a particular level of significance if the absolute value of Z is greater than $Z_{\alpha/2}$, where $Z_{\alpha/2}$ is obtained from the standard normal cumulative distribution tables. Hobbins et al. (2001a)noted that the Mann-Kendall test is non-dimensional and does not quantify the scale or the magnitude of the trend but the direction of trend.

In estimating the true slope of the trend, the Sen's nonparametric method was used. The Sen's method can be used in cases where the trend can be assumed to be linear.

3. RESULTS AND DISCUSSIONS

3.1. Temporal Trends in Evapotranspiration

The Non-Parametric Mann-Kendall and Sen's test was applied to test the trend i.e. the increase or decline in evapotranspiration of the values estimated from the FAO56 model. The ET_o values estimated were separated into two components; they are the Aerodynamic part and the Radiative part. The Non-parametric test was also applied to these terms to help ascertain which of these two parts contributes majorly to the direction of trend for estimated ET_o Values. This trend was determined for the three (3) stations at Ibadan, Kano and Onne.

3.2. Evapotranspiration Trends for Ibadan

The summary of the temporal analysis for Ibadan is given in Table 1. Monthly values of ET_o declined between the ranges of 1.51% in January to 3.8% in July.

Table 1: Non-parametric Mann-Kendall and Sen's test summary statistics for Ibadan

Month	Rad Term (mmday^{-1})			Aero Term (mmday^{-1})			Evapotranspiration (mmday^{-1})		
	%Change	Sig	Slope	%Change	Sig	Slope	%Change	Sig	Slope
JAN	-3.582	***	-0.014	0.422		0.004	-1.512		-0.012
FEB	-4.427	***	-0.021	-0.232		-0.002	-3.092	**	-0.023
MAR	-2.656	**	-0.014	-0.558		-0.003	-2.901	**	-0.022
APR	-3.637	***	-0.019	-0.586		-0.002	-3.337	***	-0.021
MAY	-3.392	***	-0.013	-1.784	+	-0.003	-3.337	***	-0.017
JUN	-3.582	***	-0.015	-1.539		-0.004	-3.310	***	-0.019
JUL	-2.983	**	-0.015	-2.574	*	-0.006	-3.800	***	-0.022
AUG	-2.738	**	-0.015	-3.119	**	-0.008	-3.555	***	-0.022
SEP	-3.446	***	-0.016	-1.975	*	-0.005	-3.392	***	-0.021
OCT	-3.528	***	-0.016	-2.111	*	-0.005	-3.664	***	-0.022
NOV	-3.855	***	-0.017	-0.368		-0.001	-3.092	**	-0.018
DEC	-3.610	***	-0.012	0.667		0.002	-3.228	**	-0.012
ANNUAL	-4.454	***	-0.015	-0.722		-0.002	-4.045	***	-0.020

*** significant at 0.001, ** significant at 0.01, * significant at 0.05, + significant at 0.1(change & slope is yr^{-1})

Rad Term: radiative part of evapotranspiration; Aero Term: aerodynamic part of evapotranspiration

These reductions were significant at P<0.01 in all the months except for January. The annual ET_o declined significantly (P<0.001) at 4.05% over the 36 years. For the radiative term, monthly values declined significantly (P<0.01) between the ranges of 2.66% in March to 4.42% in February and it annual value significantly (P<0.001) reduced by 4.45%. The aerodynamic term declined in every month except for January (0.42%) and December (0.67%) which increased, insignificantly. The decline was between 0.23% in February and 3.12% in August, which were significant at P<0.1 in the months that showed a decrease in their aerodynamic term except for the months of February, March, April, June and November. The aerodynamic term decreased at 0.72% over the 36 years but it was not significant.

3.3. Evapotranspiration Trends for Kano

Table 2 shows the summary statistics of non-paramertric trend test for Kano. There is a non-significant decline in monthly ET_o values in all the months except for the months of May, June, August and September, which indicates a non-significant increase in ET_o values.

Table 2: Non-parametric Mann-Kendall and Sen's test summary statistics for Kano

Month	Rad Term (mmday^{-1})			Aeroterm (mmday^{-1})			Evapotranspiration (mmday^{-1})		
	%Change	Sig.	Slope	%Change	Sig.	Slope	%Change	Sig.	Slope
JAN	0.506		0.003	-0.281		-0.007	-0.319		-0.011
FEB	0.882		0.007	0.000		-0.001	-0.206		-0.010
MAR	1.144		0.010	-1.219		-0.031	-0.994		-0.053
APR	0.169		0.003	-0.957		-0.036	-0.994		-0.033
MAY	1.069		0.017	0.394		0.011	0.544		0.025
JUN	1.144		0.015	-0.506		-0.006	0.769		0.016
JUL	0.469		0.005	-1.107		-0.009	-0.356		-0.004
AUG	1.257		0.011	-1.782	+	-0.010	0.506		0.004
SEP	2.682	**	0.026	-1.707	+	-0.020	0.244		0.002
OCT	2.082	*	0.025	-1.219		-0.042	-0.469		-0.013
NOV	2.045	*	0.014	-0.844		-0.020	-0.431		-0.012
DEC	-0.169		-0.001	-0.506		-0.012	-0.506		-0.006
ANNUAL	0.469		0.003	-1.144		-0.021	-0.544		-0.011

**significant at 0.01, * significant at 0.05, + significant at 0.1(change and slope is yr^{-1})

Rad Term: radiative part of evapotranspiration; Aero Term: aerodynamic part of evapotranspiration

The reduction values ranges from 0.21% in February to 0.99% in March and April over the 29 years considered, while the increase ranges from 0.24% in September to 0.77 % in June. The ET_o rate declined non-significantly at 0.54% over the 29 years. The analysis of the radiative term portrayed an increase in all the months except for December that showed a decrease (non-significant with value of 0.17% over 29 years). The increase was not significant in all the months except for the months of September, October and November which were significant (P<0.05) over the range 0.17% in April to 2.68% in September. The annual radiative term also showed a non-significant increase with a value of 0.47% over 29 years. In case of the aerodynamic term, the analysis gave a decrease in its value in all the months except for the month of May which showed an increase (non-significant) at the rate of 0.39% over 29 years and February, which indicated no change. The decrease in the other months were non- significant except for the months of August and September (P<0.1) and the decline value ranges from 0.28% in January to 1.78% in August. Its annual value depicted a non-significant decline rate of 1.14% over the 29 years.

Table 3: Non-parametric Mann-Kendall and Sen's test summary statistics for Onne

Month	Rad term (mmday^{-1})			Aero Term (mmday^{-1})			Evapotranspiration (mmday^{-1})		
	%Change	Sig.	Slope	%Change	Sig.	Slope	%Change/yr	Sig.	Slope
JAN	-1.360		-0.007	0.306		0.0018	-1.360		-0.007
FEB	-1.972	*	-0.009	0.544		0.0030	-1.972	*	-0.009
MAR	-1.428		-0.006	-0.544		-0.0032	-1.428		-0.006
APR	-0.374		-0.002	-0.986		-0.0039	-0.374		-0.002
MAY	-1.190		-0.006	0.136		0.0003	-1.190		-0.006
JUN	-1.768	+	-0.010	-0.204		-0.0006	-1.768	+	-0.010
JUL	-0.680		-0.008	0.238		0.0005	-0.680		-0.008
AUG	-1.564		-0.007	0.646		0.0004	-1.564		-0.007
SEP	-2.447	*	-0.013	0.238		0.0002	-2.447	*	-0.013
OCT	-0.986		-0.005	-0.442		-0.0008	-0.986		-0.005
NOV	-1.360		-0.006	-0.102		-0.0004	-1.360		-0.006
DEC	-1.462		-0.009	-0.017		-0.0001	-1.462		-0.009
ANNUAL	-1.870	+	-0.008	0.000		0.0000	-1.870	+	-0.008

* significant at 0.05, + significant at 0.1(change and slope is yr^{-1})

Rad Term: radiative part of evapotranspiration; Aero Term: aerodynamic part of evapotranspiration

3.4. Evapotranspiration Trends for Onne

At Onne, the analysis of the ET values showed a non-significant monthly decline except for the months of February, June and September with significant (P<0.1) decrease. The monthly value reduced over the range of between 0.37% in April and 2.45% in September. Annual ET value decreased at the rate of 1.87% over the 31 years (1989 – 2006). This reduction is significant (P<0.1), as shown in Table 3. Also from the table, it could be seen that the radiative term had similar results to that of ET in terms of values and significances while the aerodynamic term showed a decrease in value for March, April, June, and October to December and ranged from 0.02% in December to 0.99% in April. Aero term increased in trend in January, February, May and July to September with its range from 0.14% in May to 0.65% in August. These changes were not statistically significant. The analysis of the annual aerodynamic terms showed change in its trend over 31 years but this was also not statistically significant.

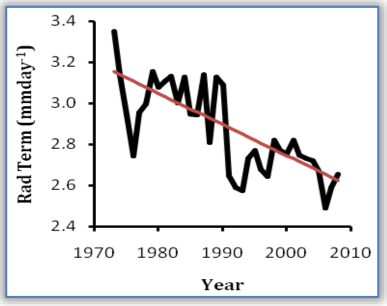

Figure 1(a): Annual trend of radiation term of evapotranspiration for Ibadan

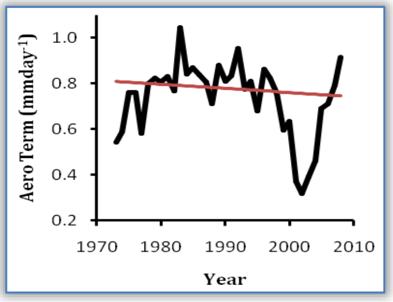

Figure 1 (b): Annual trend of Aerodynamic term of evapotranspiration for Ibadan

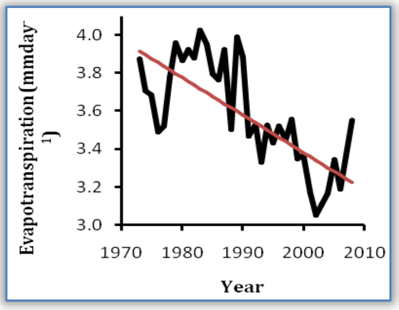

Figure 1 (c): Annual Evapotranspiration trend for Ibadan (1973 – 2008)

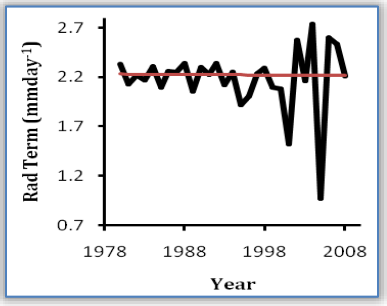

Figure 2 (a): Annual trend of radiation term of evapotranspiration for Kano

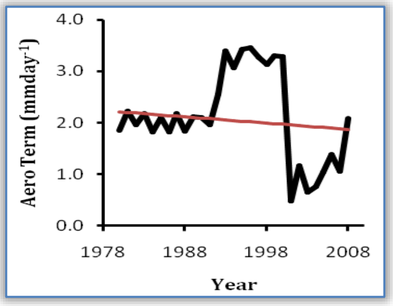

Figure 2 (b): Annual trend of Aerodynamic term of evapotranspiration for Kano

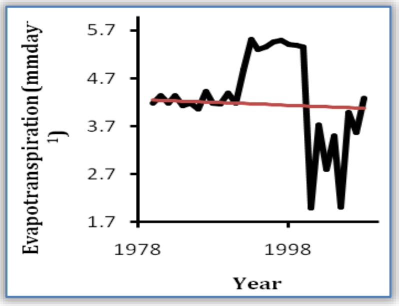

Figure 2 (c): Annual Evapotranspiration trend for Kano (1980 – 2008)

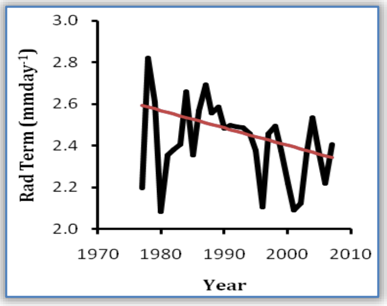

Figure 3 (a): Annual trend of radiation term of evapotranspiration for Onne

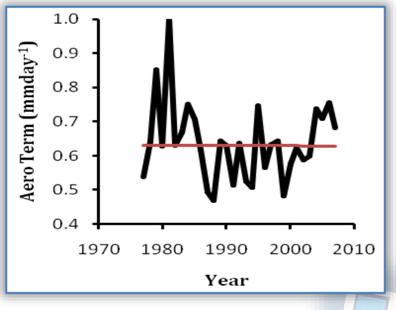

Figure 3 (b): Annual trend of Aerodynamic term of evapotranspiration for Onne

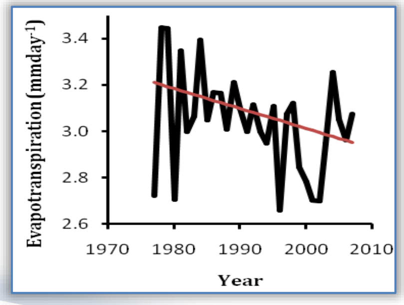

Figure 3 (c): Annual Evapotranspiration trend for Onne (1977 – 2006)

The annual time series of ET_o, the radiative and aerodynamic terms for the station are also shown in figures 1-3. These figures further explain the trend of ET_o and its component parts over the years under consideration.

3.5. Observed Trends

A general decline in ET_o values over the periods and stations considered were observed. This decline was significant for Ibadan at 0.001 levels, for Onne at 0.1, except for Kano with an insignificant decrease.

At Ibadan, it was observed from the component parts of ET_o that there was a significant decrease in the values of the radiative term and an insignificant decrease in the aerodynamic term. It can be concluded that the reduction in the values of the radiative term which is majorly derived from solar radiation is the major contributor to the decline in ET_o for Ibadan. This agrees with a similar research carried out in China which showed that the widespread decline of pan evaporation was as a result of decreasing solar irradiance (Liu et al., 2004). Previous studies showed that evapotranspiration and pan evaporation have similar regional distribution patterns (Xu et al., 2006).

At Kano, there was a little reduction in ET_o rate over the period considered for this study. This reduction was not significant and in this case, there was an increase in the radiative term as against the reduction in this term observed in Ibadan. On the other hand, the aerodynamic term reduced in all the months and the annual average which agreed with the reduction in ET_o rate. It could be deduced from the result that the major cause of the decline in ET_o trend for Kano is the aerodynamic term of the ET_o which was mainly influenced by reduction in wind speed. These findings agree with a similar study carried out in China which showed a decreasing trend of ET which was largely caused by the decrease in solar radiation followed by the decrease in wind speed (Xu et al., 2006). It also showed from the increase in the radiative term that the effect of climate change is more pronounced in this part of the country in the aspect of increasing temperature, reduction in cloud cover, leading to increase solar radiation.

This decrease in ET_o with an observed increase in solar radiation contradicts results obtained for similar researches carried out in some parts of the world. For example in Canada, ET_o showed an increasing trend which was as a result of increase in air temperature and solar radiation (Fernandez et al., 2007).

In Onne, the ET_o rate showed a decline in its trend, and from the results obtained from the analysis, the annual aerodynamic term had no change over the period considered and it could be seen that the decline in ET_o rates was mainly influenced by the decline in the radiative component of ET_o and this was significant at 0.1.

4. CONCLUSIONS

The overall results obtained from this work indicate that the ET_o rate is decreasing across the country. This decline was found at the three stations with Ibadan exhibiting the largest decline followed by Onne and Kano in that order. The study also showed that the declines in Ibadan and Onne occurred majorly due to the reduction in solar radiation while in Kano, it was caused by reducing aerodynamic parameters (wind).This study has been able to establish the trend of estimated ET_o over Nigeria which is towards the negative/decreasing direction. This information will to a very large extent be of good use to water resources management personnel.

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