Trend analysis of reference evapotranspiration: case study of Asaba and Uyo, South-South Nigeria

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Abstract: Temporal trend analysis of monthly mean reference evapotranspiration (RET) estimates using FAO-56 PM model was performed using the Non-Parametric Mann-Kendall (MK) and Sen's test for Asaba and Uyo over the period of 41 and 35 years respectively. In Asaba, RET showed an overall increasing trend, ranging from MK Z values from 0.80 to 2.93 except for June (-0.75) and September (-1.16) which declined insignificantly. For Uyo, RET showed an insignificant decreasing trend (p>0.1) with MK Z values ranging from -0.09 to -1.65 except for November (0.91) which insignificantly increased at p>0.1. For a detailed evaluation of the trends, RET was separated into aerodynamic and radiation terms and their trend analysis were performed. In Asaba, the radiation term showed a general decreasing trend (ranging from MK Z values from -0.42 to -2.84) except for July (0.42) and August (0.46) which have an insignificant increasing trend. The aerodynamic term increased in every month with MK Z values ranging from 0.64 to 2.17. The temporal study of the component terms in Uyo showed a more significant trend than the RET trend. The radiation term trend increased in p-value of 0.01 (0.31 to 1.85) whereas the aerodynamic term trends significantly decreased (-0.86 to -3.04). It was also deduced that the general RET trend and the aerodynamic trend are of the same over the period of study. This implies that, aerodynamic parameters most especially the wind speed and the saturation vapour pressure have more effect on RET in the two study areas.

Keywords: reference evapotranspiration (RET), trends, FAO-56 PM Model, Mann-Kendall, Sen, meteorological

Citation: Umego, O. M., T. A. Ewemoje and H. A. Alabi. 2020. Trend analysis of reference evapotranspiration: case study of Asaba and Uyo, South-South Nigeria: CIGR Journal, 22(4): 1-8

1 Introduction

Climatic change is an undeniable fact and may accelerate hydrological cycles and redistribute global water resources. It has been reported since 2007 by the Intergovernmental Panel on Climate Change (IPCC) that climate change is occurring worldwide. This was confirmed in their fifth report (IPCC, 2014) as global warming is unequivocal, its effects are already being felt in all environments and sectors which include health, agriculture, ecosystems, water, land and ocean on all continents, from small islands to large continents. Although climate change occurred on a global scale, its impacts often vary from region to another (Gocic and Trajkovic, 2013).

Furthermore, there is substantial evidence to suggest that the hydrologic cycle has been intensifying with climate change (Kramer et al., 2015). These have raised questions like: How is this hydrologic intensification being distributed across the cycle? To which components of the cycle have the additional precipitation been directed? What are the implications of these changes in the climate? Countries that already suffer from severe

Received date: 2019-07-05 **Accepted date:** 2019-11-21

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climatic condition like aridity, limited economic development options like exploitation of water, priority sector to promote the agriculture and agro-based industry to meet the needs of the people are the ones most severely affected by climate change.

According to Ma et al. (2017), climatic change has been identified not only in individual parameters such as temperature and precipitation, but also in integrated parameters like reference evapotranspiration (RET). RET is one of the vital components of the hydrological cycle and controls the energy and mass exchange between terrestrial ecosystems and the atmosphere. It is influenced by many factors which include climate factors (temperature, solar radiation), crop factors like (crop pattern, cropping system), environmental conditions and water resource management. Evapotranspiration (ET) is considered the most significant indicator for climate change and the water cycle as it is the only connection linking the water balance and the land surface energy balance (Wang et al., 2014).

Despite that climate warming is almost confirmed worldwide, the evapotranspiration trend is not obvious. Depending on climatic conditions and regions, ET trends may be increasing or decreasing (Rim, 2009). According to Mansour et al. (2017), some studies indicated that the evapotranspiration trend is not determined only by temperature (Xu et al., 2006; Ohmura and Wild, 2002). Other studies have shown a decrease in the evapotranspiration trend over the past decades in many places of the world (Gao et al., 2007; Darshana et al., 2013; Irmak et al., 2012). However, some have reported the opposite phenomenon that is increase in evapotranspiration trend (Tabari et al., 2011; Kousari et al., 2013; Hosseinzadeh Talaee et al., 2014). Therefore, it is very important to understand RET trends and their role in regional dry and wet conditions. This could give a scientific basis for regional water resource management and allocation and for the scientific decision-making of preventing flood and drought disaster (Ma et al., 2017). This study, therefore, seeks to perform temporal trend analysis of RET estimated with FAO-56 Penman-Monteith equation in Asaba and Uyo to ascertain their trends over the study period.

2 Materials and method

2.1 Location and description of the study area

The two locations considered in this study are Asaba and Uyo, both are located in the south southern part of Nigeria. Asaba the capital of Nigeria's Delta State with coordinates 6°11′52.23″N and 6°43′42.48″E is situated on a terrace of the western edge of the Niger River forming a connection between western, eastern and northern Nigeria through the Niger River from the north and via the Asaba Niger Bridge, an east-west link and a Nigerian landmark. It lies approximately 60 degrees north of the equator and about the same distance east of the meridian; about 160 kilometers north of where the River Niger flows into the Atlantic Ocean. The greater Asaba occupies an area of about 300 square kilometers. It maintains an average tropical temperature of 32℃ during the dry season and an average fertile rainfall of 2,700 mm during the rainy season.

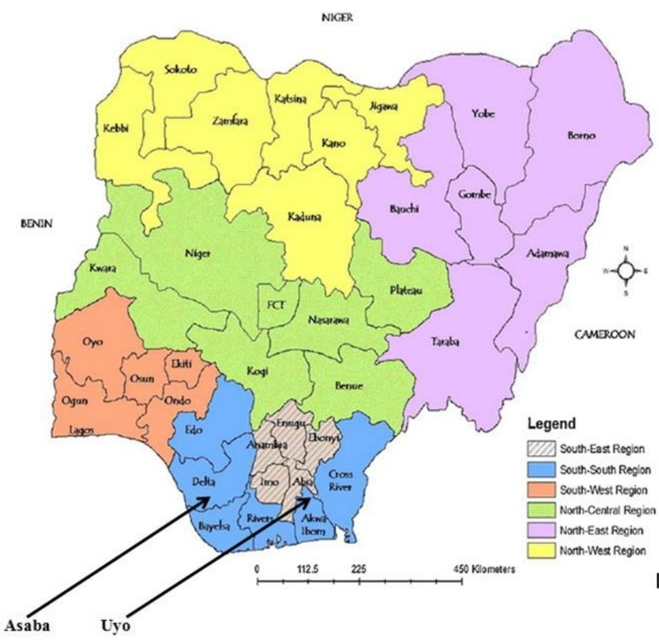

Figure 1 Map of Nigeria indicating Uyo and Asaba

Uyo, the capital of Akwa-Ibom State of Nigeria with coordinates 5°2′N and 7°55′E is located within the equatorial region. It is located about 60 km from the coast of the Atlantic Ocean. The rainfall is of the double maxima regime with a break occurring in August. Mean annual rainfall stands at about 2400 mm. Uyo is characterized by a uniform temperature all through the year with a mean high of about 28℃ recorded between March/April and a mean low of about 25℃ is recorded around August. Relative humidity is equally high with a seasonal variation component. The low relative humidity about 54% is recorded in January and it keeps increasing to about 84% in July. The high relative humidity in the area can be attributed to its proximity to the Atlantic Ocean.

2.2 Data used

Records of climatic variables, including solar radiation, maximum and minimum temperature, relative humidity, sunshine hours and wind speed, all in monthly average were collected from the Nigeria Meteorological Agency (NIMET), Abuja. For Asaba and Uyo stations with elevations of about 97.6 m and 38.0 m above Mean Sea Level (MSL), 41-years (1975 – 2015) and 35-year (1981 – 2015) records were obtained respectively.

2.3 Methods of analysis

RET was calculated using the FAO-56 Penman-Monteith model (Equation 1). This model was adjudged by the Food and Agricultural Organization (FAO) to be the best estimator of RET. It is considered the best because it encompasses the physical parameters that govern the exchange of aerodynamic, energy and physiological aspects of culture (Obioma et al., 2015; Ewemoje and Okanlawon, 2015) and when compared with other models, it has a better performance in many regions of the world (Ilesanmi et al., 2014). Owing to this, it has been adopted as the sole model to be used for estimation of RET from meteorological data.

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

The above equation is divided into two parts: radiation part and aerodynamic part (Equation *2a* and *2b* respectively) which their summation gives the RET of the FAO-56 PM model.

$$ET_o rad = \frac{0.408\Delta(R_n - G)}{\Delta + \gamma(1 + 0.34u_2)} \quad (2a)$$

$$ET_o aero = \frac{\gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (2b)$$

Where: ET_O is RET in mm day^{-1}, R_n is the net radiation at the crop surface in MJ m^{-2} day^{-1}, G is soil heat flux density in MJ m^{-2} day^{-1}, T is mean daily air temperature at 2 m height in ℃, u_2 is wind speed at 2 m height in m s^{-1}, e_s is the saturation vapour pressure in kPa, e_a is actual vapour pressure in kPa, $e_s - e_a$ is saturation vapour pressure deficit in kPa, Δ is a slope vapour pressure curve in kPa ℃$^{-1}$ and γ is psychrometric constant kPa ℃$^{-1}$.

2.3.1 Mann-Kendall test

For the analysis of trend in hydrologic and climatologic time series, Mann-Kendall statistic test is broadly used. It has been recommended by the World Meteorological Organization (WMO) to find out the actuality of statistically significant trends in climate and hydrology data time series. The advantage of this test is that it does not compulsorily require the data to be normally distributed (Achugbu and Anugwo, 2016). In the test, the null hypothesis of no trend, H_0, is tested against the alternative hypothesis, H_1, where there is either an increasing or decreasing monotonic trend (i.e., the trend is consistently increasing or decreasing).

The Mann-Kendall test statistic S according to Salmi et al. (2002) is given by

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k) \quad (3)$$

Where: x_j and x_k is annual values in years j and k, $j > k$, respectively, n is length of the time series x_i, …, x_n,

$$\operatorname{sgn}(x_j - x_i) = sign\ function = \begin{cases} 1 \ if \ x_j - x_k > 0 \\ 0 \ if \ x_j - x_k = 0 \\ -1 \ if \ x_j - x_k < 0 \end{cases}$$

The variance of S is computed by the following equation:

$$\sigma^2(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p-1}^{q} t_p (t_p - 1)(2t_p + 5) \right] \quad (4)$$

Where: q is number of tied groups, t_p is number of data values in pth group.

The test statistic Z is then given as:

$$Z=\begin{cases}\frac{S-1}{\sqrt{VAR(S)}} & if\ S>0\\ 0 & if\ S=0\\ \frac{S+1}{\sqrt{VAR(S)}} & if\ S<0\end{cases} \quad (5)$$

The Z statistic is 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 value of Z indicates an upward (increasing) monotone trend while a negative value indicates a downward (decreasing) 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 gotten from the standard normal cumulative distribution tables. The tested significance levels in this study are 0.1, 0.05, 0.01 and 0.001.

2.3.2 Sens's slope estimator

The Sen's slope estimator uses a simple, non-parametric procedure to estimate the true slope of the trend that is changing per unit time period. To obtain an estimate of the slope Q, the slope Q_i of all data pairs are calculated as follows:

$$Q_i = \frac{x_j - x_k}{j-k} \quad (6)$$

i = 1, 2,... N, j >k

$$Q = Q_i \frac{N+1}{1}\ If\ N\ is\ odd \quad (7)$$

$$Q = \frac{1}{2}\left(Q_i \frac{N}{2} + Q\frac{N+2}{2}\right) if\ N\ is\ even \quad (8)$$

Positive value of Q_i denotes an upward or increasing trend and a negative value shows a downward or decreasing trend in the time series.

3 Results and discussion

The Non-Parametric Mann-Kendall (MK) and Sen's test was applied to test the trend i.e. the increase or decline in evapotranspiration of the values estimated from the FAO-56 model for the study period. The RET values estimated were separated into two components; they are the Aerodynamic term and the Radiation term. The test was also applied to these terms for detailed evaluation of the trends. This trend was determined for each station, Asaba and Uyo.

3.1 Evapotranspiration trends for Asaba

From Figure 2, the monthly values of RET of the period of study 1975 – 2015 showed an overall increasing trend, ranging from MK Z values from 0.80 to 2.93 except for June (-0.75) and September (-1.16) which declined insignificantly (Table 1). As shown in Table 1, the monthly RET trend increased significantly at P<0.01 in February (2.59), March (2.73) and December (2.93); P<0.05 in January (2.44) and July (2.21); P<0.1 in October (1.90) and November (1.81). The significant increase could be because, within the study period, there was increase in temperature and solar radiation, which are some of the major factors that affect ET (Malekinezhad, 2012; Isikwue et al., 2014). Other months (April, May and September) increased insignificantly at P>0.1. The total RET for Asaba range from 40.1 mm day^{-1} in 2009 to 55.0 mm day^{-1} in 2010.

For the radiation term, the monthly values showed a general decreasing trend as also seen in Figure 3 except for July (0.42) and August (0.46) which have an insignificant increasing trend. The monthly radiation decreasing trend was only significant at P<0.01 in June (-2.84) and P<0.05 in September (-2.01). Other months declined insignificantly at P>0.1 ranging from -0.42 to -1.38.

The aerodynamic term over the study period increased in every month (Table 1) with MK Z values ranging from 0.64 to 2.17. This increasing trend was significant at P<0.05 in February (2.06) and March (2.17); P<0.1 in January (1.67), April (1.65), July (1.79) and December (1.76). The remaining months increased insignificantly at P>0.1 with Z values ranging from 0.64 to 1.49. The increasing trend of aerodynamic term for Asaba is shown in Figure 4.

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

Month	First Year	Last Year	Radiation Term (mm day^{-1})			Aerodynamic Term (mm day^{-1})			Evapotranspiration (mm day^{-1})		
			Test Z	Sig.	Slope	Test Z	Sig.	Slope	Test Z	Sig.	Slope
Jan	1975	2015	-0.89		-0.003	1.67	+	0.016	2.44	*	0.017
Feb	1975	2015	-0.98		-0.004	2.06	*	0.016	2.59	**	0.021

Mar	1975	2015	-0.95		-0.005	2.17	*	0.018	2.73	**	0.019
Apr	1975	2015	-0.82		-0.003	1.65	+	0.009	1.02		0.007
May	1975	2015	-1.38		-0.003	0.93		0.005	0.80		0.004
Jun	1975	2015	-2.84	**	-0.010	0.75		0.003	-0.75		-0.004
Jul	1975	2015	0.42		0.001	1.79	+	0.008	2.21	*	0.009
Aug	1975	2015	0.46		0.002	0.78		0.003	1.18		0.005
Sep	1975	2015	-2.01	*	-0.008	0.64		0.002	-1.16		-0.005
Oct	1975	2015	-0.71		-0.002	1.49		0.006	1.90	+	0.010
Nov	1975	2015	-0.42		-0.002	0.98		0.005	1.81	+	0.010
Dec	1975	2015	-1.16		-0.004	1.76	+	0.012	2.93	**	0.015

Note: ***trend at a = 0.001 level of significant; ** trend at a = 0.01 level of significant; * trend at a = 0.05 level of significant; + trend at a = 0.1 level of significant; Sig. = significance.

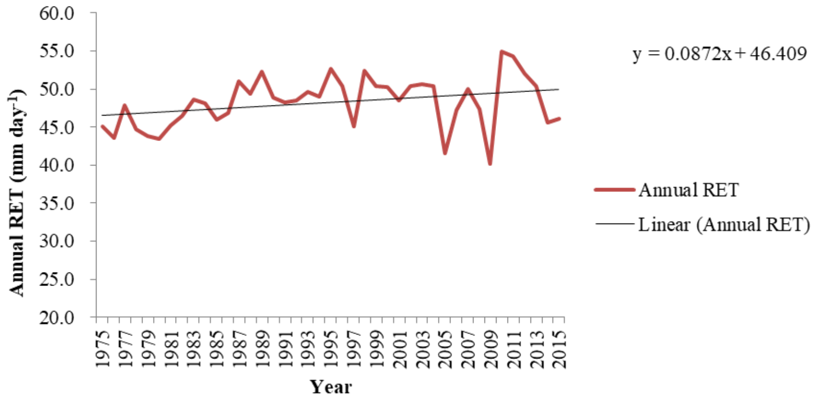

Figure 2 Annual RET trend for Asaba (1975 – 2015)

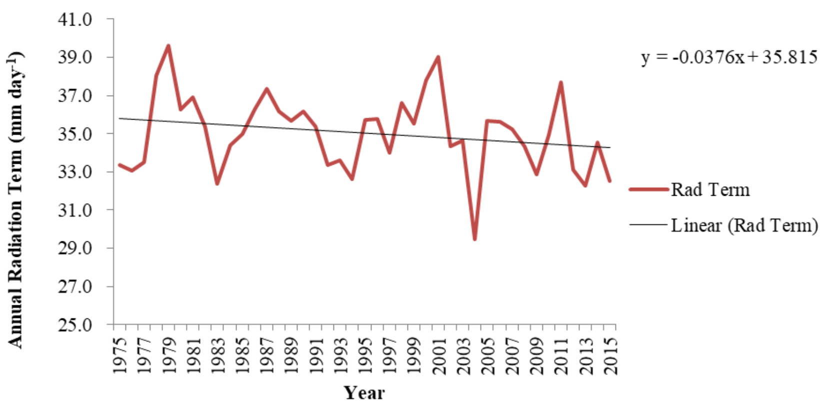

Figure 3 Annual trend of radiation term of evapotranspiration for Asaba (1975-2015)

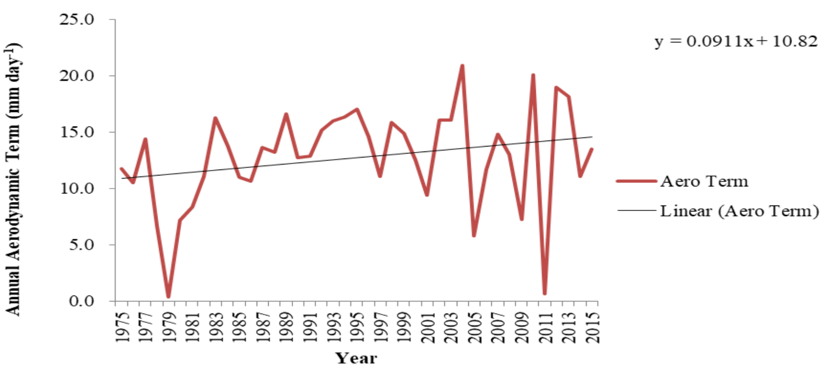

Figure 4 Annual trend of aerodynamic term of evapotranspiration for Asaba (1975-2015)

3.2 Evapotranspiration trends for Uyo

Table 2 shows the summary statistics of non-parametric temporal trend analysis for Uyo. For the period of study, RET showed an insignificant decreasing trend (P>0.1) (observed in Figure 5) with MK Z values ranging from -0.09 to -1.65 except for November (0.91) which insignificantly increased at P>0.1. The monthly RET trend only declined significantly at P<0.1 in March (-1.65) may be as a result of decrease in solar radiation and temperature over the study period. The maximum total ET for Uyo is 49.45 mm day^{-1} in 2005 while the minimum total ET is 34.39 mm day^{-1} in 2014.

The trend analysis of the radiation term portrayed an increase in all the months except for January (-0.94), February (-0.20), March (-0.97) and December (-1.53) which insignificantly declined at P>0.1. The increasing trend was only significant at P<0.1 in May (1.85), June (1.82) and October (1.73). The remaining months (April, June, August, September and November) insignificantly increased at P>0.1 ranging from 0.31 to 1.51. The radiation trend of Uyo which generally increased for the study period can also be seen in Figure 6.

In the case of aerodynamic term, the trend analysis over the study period decreased in every month except for November (0.43) and December (0.65) which increased insignificantly and January (0.00) which has no trend. The decreasing trend was significant at P<0.01 in June (-3.04); P<0.05 in April (-2.41), May (-2.24) and September (-2.19); P<0.1 in July (-1.96) and August (-1.65). The remaining months (February, March and October) decreased insignificantly at P>0.1 with Z values ranging from -0.88 to -1.51. The decreasing trend of aerodynamic term for Uyo is shown in Figure 7.

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

Month	First Year	Last Year	Radiation Term (mm day^{-1})			Aerodynamic Term (mm day^{-1})			Evapotranspiration (mm day^{-1})		
			Test Z	Sig.	Slope	Test Z	Sig.	Slope	Test Z	Sig.	Slope
Jan	1981	2015	-0.94		-0.005	0.00		0.000	-0.77		-0.005
Feb	1981	2015	-0.20		-0.001	-0.91		-0.012	-1.11		-0.013
Mar	1981	2015	-0.97		-0.006	-1.51		-0.016	-1.65	+	-0.022
Apr	1981	2015	1.05		0.005	-2.41	*	-0.016	-1.11		-0.012
May	1981	2015	1.85	+	0.010	-2.24	*	-0.013	-0.80		-0.005
Jun	1981	2015	1.82	+	0.008	-3.04	**	-0.015	-1.53		-0.010
Jul	1981	2015	0.68		0.002	-1.96	+	-0.009	-1.62		-0.009
Aug	1981	2015	0.31		0.003	-1.65	+	-0.007	-1.59		-0.008
Sep	1981	2015	1.51		0.007	-2.19	*	-0.010	-0.94		-0.005
Oct	1981	2015	1.73	+	0.008	-0.88		-0.005	-0.09		0.000
Nov	1981	2015	1.28		0.006	0.43		0.002	0.91		0.005
Dec	1981	2015	-1.53		-0.009	0.65		0.007	-0.17		-0.002

Note: ***trend at a = 0.001 level of significant; ** trend at a = 0.01 level of significant; * trend at a = 0.05 level of significant; + trend at a = 0.1 level of significant; Sig. = significance.

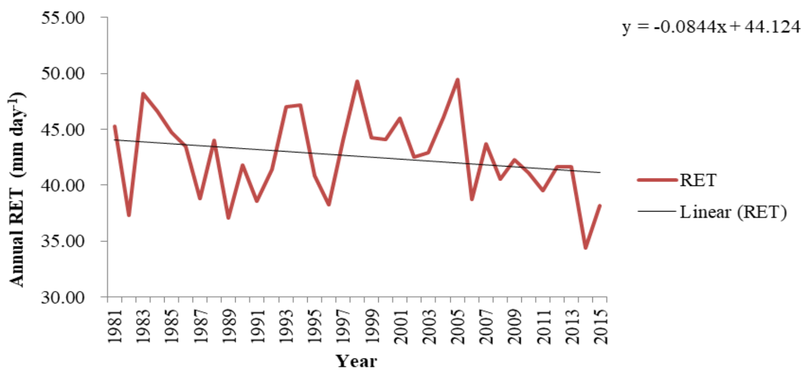

Figure 5 Annual RET trend for Uyo (1981 – 2015)

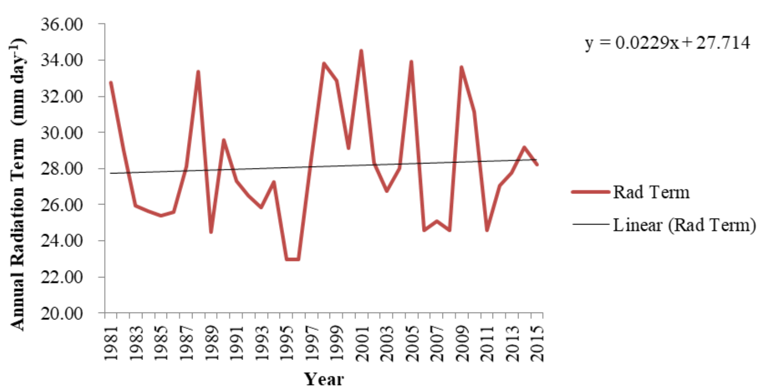

Figure 6 Annual trend of radiation term of evapotranspiration for Uyo (1981-2015)

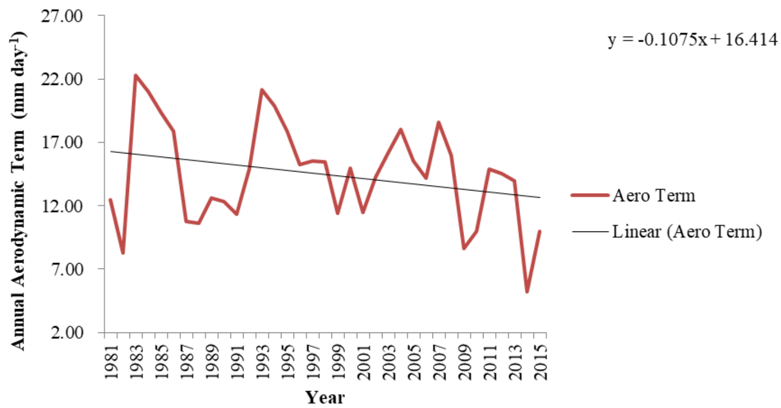

Figure 7 Annual trend of Aerodynamic term of evapotranspiration for Uyo (1981-2015)

3.3 Discussion on observed trends

The temporal study of the RET in the two study locations Asaba and Uyo which was assumed to have almost similar climatic conditions showed no definite monotonic trend over the study period. The two trends were in opposite directions; increasing in Asaba and decreasing in Uyo. This indicates and implies that climatic change is specific to locations and therefore should not be generalized. The location under consideration should always be studied independently.

The temporal study of each component part of RET (aerodynamic and radiation term) for the two locations showed a more statistically significant trend than the RET trend. The two terms trend was in the opposite direction to each other. In Asaba, a decreasing trend of the radiation term was recorded against an increasing trend of aerodynamic term. In Uyo, the two terms were also in opposite directions; the radiation term showed an increasing trend over the study period, while the aerodynamic term showed a significant declining trend. These finding agree with a similar study carried out in Tunisia which showed an opposite direction, trends of the two component terms of ET (Mansour et al., 2017).

From the results in both locations, it could be deduced that the general RET trend and the aerodynamic trend are of the same over the period of study. In Asaba, the aerodynamic trend increased significantly and so do the RET trend. In Uyo as well, there was significantly declining trend of the aerodynamic term which also applied to the RET trend though it was not all that significant. This implies that, aerodynamic parameters most especially the wind speed and the saturation vapour pressure as shown in Equation 2b have more effect on RET in the two study areas which are both located in the south southern part of Nigeria.

4 Conclusion

Temporal trend analysis of RET estimates using FAO-56 PM model was performed using the Non-Parametric Mann-Kendall and Sen's test for Asaba and Uyo. The results obtained from the work shows a statistically significant increasing RET trend in Asaba over the study period having RET total maximum as 55.0 mm day^{-1} in 2010 and its minimum as 40.1 mm day^{-1} in 2009. This increasing trend could be as a result of the increasing aerodynamic parameters over the years as observed when RET was separated into its two component terms. In Uyo, the RET trend decreased insignificantly in line with the aerodynamic parameters with maximum total RET as 49.45 mm day^{-1} in 2005 and minimum as 34.39 mm day^{-1} in 2014. The radiation trends in the two study locations were in the opposite direction of the aerodynamic trends.

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